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Academician, Russian Academy of Sciences
Counsellor of the Presidium of the Russian Academy of Sciences

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Evolution of the biosphere

The Evolution of Terrigenous Rocks in the Late Precambrian

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Abstract – A sample of more than 4000 silicate analyses of the Riphean and Vendian shales, siltstones, and sandstones of the Russian platform, the Urals, the Siberian platform, and the surrounding fold structures was statistically processed and the results were compared with corresponding data on the Phanerozoic. The data obtained reveals that the average composition of terrigenous rocks during the Late Precambrian and Early Paleozoic were relatively constant, and, in addition, that a sudden change occurred in their composition at the transition from the Middle-Late Paleozoic to the Mesozoic–Cenozoic. This revolutionary stage in the history of terrigenous sedimentation was caused, evidently, by the advent of higher terrestrial plants, a process that changed the character of chemical weathering in the source areas primarily through a greater mobility of potassium, reducing the eolian reworking of the terrigenous material, and consequently decreased the maturity grade of the Phanerozoic sandy rocks.

INTRODUCTION

Terrigenous rocks constitute about 70% of the Earth's sedimentary cover (Ronov *et al.*, 1990a) and, therefore, the changes in their average composition through geologic history are among the most important phenomena in the evolution of sedimentation. The major part of the analytical data that forms the present basis of contemporary concepts about the petrochemical evolution of terrigenous rocks was obtained by Ronov *et al.* (Ronov *et al.*, 1970; 1990a; Vinogradov and Ronov, 1956) from detailed studies of the Phanerozoic and later of the Precambrian deposits of the Russian platform (Ronov and Kazakov, 1983; Ronov *et al.*, 1990b). A comparison of these data with the results of similar studies in other areas of the world, especially on the North American platform (Ronov and Migdisov, 1970), revealed the principal trends in the composition changes of sandy and clayey rocks in the Proterozoic and Phanerozoic periods. According to the concepts formulated as a result of these studies, the trends indicate an increase in potassium content in clayey and sandy rocks during the Archean through Paleozoic and a decrease from the Middle Paleozoic to Cenozoic. The opposite trend, however, shows a minimum of sodium content in the Lower Paleozoic. In addition, a persistent decrease in iron and the growth of Fe_2O_3/FeO and Al_2O_3/SiO_2 modules in clays throughout geologic history can be inferred. In sandy rocks, the latter module gradually loses importance (Ronov and Migdisov, 1970; Ronov *et al.*, 1990b).

Garrels and MacKenzie (1974) suggested a more generalized evolutionary scheme of clayey rock composition during the Proterozoic and Phanerozoic, i.e., a continuous decrease in potassium and ferrous iron contents in them and an increase in the content of sodium, magnesium, silica, and ferrous iron normalized to aluminum.

The purpose of our research was to conduct a detailed analysis of the Riphean and Vendian stages in the evolution of terrigenous rocks assumed in the above generalizations to be a single time interval represented graphically as a point in corresponding plots, whereas the duration of each of the three subdivisions of the Riphean is commensurable with that of the Paleozoic.

A detailed study of the Upper Precambrian terrigenous rocks on the Russian platform by Ronov *et al.* (Ronov *et al.*, 1990a; Ronov and Kazakov, 1983) produced results noticeably different from the above calculations of the general trends in the evolution of terrigenous rocks obtained by the same researchers. Applying the petrochemical data on the terrigenous deposits of the Late Precambrian of the Russian platform to characterize the sedimentation of that period, we should bear in mind that their deposition occurred within a rather narrow range of mainly continental or coastal paleogeographic environments (Ronov and Kazakov, 1983). In order to obtain a more complete characterization of sedimentation on the Late Precambrian platforms and the adjoining territories, the data on the Russian platform should be supplemented by data

on the composition of the Upper Precambrian deposits of the Siberian platform and of its framing, which is generally composed of relatively deep-water deposits of shelf seas and rift troughs. Thus, the sandy rocks obviously prevail over shales (by a ratio of about 2 : 1) in the Upper Precambrian deposits on the Russian platform whereas in the Earth's sedimentary cover as a whole their ratio is reversed (1 : 2). However, their stratigraphic analogues on the Siberian platform have an anomalously high relative volume of carbonate rocks, which is no less than double their average content in the sedimentary cover, i.e., 15% (Ronov *et al.*, 1990a, b; Serebryakov and Semikhatov, 1975), while the Upper Proterozoic sections on the larger part of the Russian platform, except its eastern margins, almost completely lack carbonate rocks. As shown below, differences in the environmental (including climatic) settings affected the chemical composition of the deposits; this supplementary data helps to clarify our understanding of the peculiarities present during the evolution of terrigenous sedimentation in the Late Precambrian.

DATA AND METHODS

Our generalization is based on the results of 4474 analyses of the contents of petrogenic and certain minor elements in single samples of terrigenous rocks, i.e., sandstones (1675), siltstones (820), and shales (1979). We obtained about half of the analyses while studying the geochemistry of the rocks from the stratotype and reference sections of the Upper Precambrian, including the Vendian deposits of the Moscow syneclise and the L'vov–Kishinev depression of the Russian platform (Sochava *et al.*, 1992), the Riphean and Vendian of the Bashkirian anticlinorium, the Central Urals, the Kola Peninsula, the Uchur–Maya region, and the Patom Highland. These analysts were supplemented by the analytical data kindly provided by E.Z. Gareev (the Bashkirian anticlinorium), Ya.E. Yudovich and M. P. Ketris (the Northern and Polar Urals and Timan), L.V. Korenchuk, E.A. Pirrus, and D.V. Borkhvardt (the Vendian of the Russian platform), B.R. Shpunt (the northern Siberian platform), V.K. Nemerov (the Baikal region), and A.V. Ivanovskaya (the southwestern Siberian platform). In addition, we also used the data published by Petrov (1982) on the Sayany region, the Enisei Ridge, and the Turukhansk and Igarka uplifts. The analyses were performed in several laboratories through chemical silicate and X-ray-fluorescent analysis.

Unlike Ronov and collaborators, who analyzed the averaged samples composed of many specimens of the same rocks and the mixed samples composed of several averaged samples (Vinogradov and Ronov, 1956; Ronov *et al.*, 1990a), we used the analytical data on individual rock specimens to study the evolution of the Late Precambrian terrigenous rocks. Though more time consuming and costly, our approach has certain advantages, providing the possibility to more reliably compare chemical analyses with petrographic data from thin sections in order to establish uniform samples and a more extensive application of statistic studies of rock composition variations. In this procedure, we eliminated rocks with a considerable admixture of authigenic minerals, i.e., carbonate, ferric oxides, and phosphates, from the sample of the terrigenous rocks proper and divided them into three (not two) groups: sandstones, siltstones, and shales. We shall concentrate our subsequent discussion on sandstones and shales, the most characteristic and common components of the terrigenous rocks.

To evaluate the main trends in the evolution of terrigenous rock composition during the studied span of geologic time, we calculated the average compositions of sandstones and shales of the four main stratigraphic units of the Upper Precambrian, i.e., the Lower, Middle, and Upper Riphean and the Vendian, for the four large structural zones, i.e., the Russian platform, the adjoining western Urals fold region, the Siberian platform, and its framing fold structure. The latter includes Sette–Daban, the Baikal–Patom Highland, the Baikal area, the Sayany area, the Enisei Ridge, and the Turukhansk and Igarka uplifts. This data was used to separately calculate the average compositions of the relevant rocks for the east European and the east Siberian regions by assuming that the contribution of the rocks of the platforms and of their framing are equivalent; finally, under the same assumption, the average compositions of sandstones and shales were calculated in the indicated stratigraphic units for the entire studied territory (Table 1). This three-step calculation of the average compositions reduces the effect of irregular sampling of various stratigraphic units and regions. The calculations incorporated not only the indicated information stored at our data base, but also the data of Ronov and his collaborators (Ronov *et al.*, 1990a; Ronov and Kazakov, 1983) with due corrections for the carbonate admixture in the rocks. The presented diagrams (Figs. 1 and 2) are based on the above calculations as well as on some data on the Lower Proterozoic, i.e., the average of the mean compositions of terrigenous rocks in 33 formations derived from the sections of the Aldan (Sochava, 1986) and Baltic shields (Melezhik and Predovskii, 1982; Predovskii, 1980; Sokolov *et al.*, 1970) (449 analyses of silty-clayey rocks and 420 analyses of sandy rocks), and on the data on the compositions of the indicated rocks in the Phanerozoic sections from the Russian and North American platforms (Vinogradov and Ronov, 1956; Ronov and Migdisov, 1970).

When referring the local formations to the units of the general Precambrian scale (Table 2), we followed the Resolutions of the Ufa Stratigraphic Meeting in 1990 (Semikhatov *et al.*, 1991) and the regional stratigraphic schemes described in several publications (*Stratotip Rifeya* ..., 1983; Semikhatov and Serebryakov, 1983; *Resheniya* ..., 1983).

Table 1. Average composition of the Proterozoic terrigenous rocks of the Russian and Siberian platforms and their fold framing

Scale	Region	Rocks	Number of analyses	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Ignition losses	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Lower Proterozoic	Baltic and Aldan shields	Shales, Siltstones	499	60.62	0.81	17.15	3.17	3.67	0.09	2.93	1.20	2.01	4.60	0.14	3.04	99.43
		Sandstones	420	77.94	0.38	9.32	1.32	1.97	0.06	1.37	1.38	2.09	2.22	0.10	1.71	99.86
Lower Riphean	Russian platform	Shales*	6 (16)	54.77	0.71	14.54	4.74	1.61	0.06	3.51	4.17	1.19	5.86	0.12	8.50	99.78
	Urals	Shales	136	60.90	0.77	18.36	2.79	2.82	0.03	2.93	0.80	0.86	5.00	0.12	4.51	99.89
		Sandstones	87	83.04	0.33	7.03	1.24	1.27	0.04	0.97	0.66	0.89	2.52	0.09	1.42	99.50
	Siberian platform	Sandstones	57	91.56	0.13	3.18	1.13	0.83	0.03	0.25	0.17	0.05	1.44	0.03	0.88	99.68
	Siberian platform framing	Shales	118	59.18	0.88	20.01	2.01	5.68	0.08	2.03	0.69	1.16	4.05	0.13	4.06	99.96
		Sandstones	37	80.44	0.28	8.54	0.76	1.81	0.04	1.12	0.95	0.69	3.48	0.08	1.67	99.86
	All regions	Shales	260	59.64	0.83	18.53	2.99	3.98	0.07	2.48	0.75	1.12	4.86	0.12	4.27	99.64
		Siltstones	66	67.07	0.67	14.53	1.68	3.09	0.03	2.34	0.87	1.51	4.52	0.15	3.24	99.70
		Sandstones	181	84.52	0.27	6.45	1.10	1.30	0.04	0.83	0.61	0.63	2.49	0.08	1.35	99.67
Middle Riphean	Russian platform	Shales*	5 (53)	54.61	0.68	14.79	5.12	1.28	0.07	3.97	3.58	0.79	6.64	0.14	7.95	99.62
		Sandstones	50	80.01	0.42	9.03	1.54	0.40	0.08	1.10	0.84	1.33	3.24	0.10	2.02	100.11
	Urals	Shales	137	60.95	0.94	19.06	2.80	2.94	0.11	2.41	0.71	0.71	5.37	0.09	3.80	99.89
		Sandstones	129	86.67	0.30	5.54	1.19	1.61	0.03	0.70	0.39	0.48	1.45	0.08	1.26	99.70
	Siberian platform framing	Shales	346	59.51	1.01	19.11	2.09	5.47	0.10	2.28	0.76	1.49	3.73	0.13	4.03	99.71
		Sandstones	110	82.38	0.40	7.41	0.94	2.54	0.07	1.02	1.03	1.18	1.38	0.08	1.45	99.88
	All regions	Shales	488	59.87	0.93	18.35	3.14	3.82	0.10	2.35	0.74	1.14	5.02	0.12	3.99	99.57
		Siltstones	108	67.05	0.82	14.80	2.06	3.49	0.06	1.88	1.01	1.73	3.39	0.12	3.03	99.44
		Sandstones	289	82.86	0.38	7.36	1.16	1.76	0.07	0.96	0.83	1.05	1.86	0.09	1.55	99.93

Table 1. (Contd.)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Upper Riphean	Russian platform	Shales*	13 (125)	57.13	0.75	15.45	5.44	1.35	0.07	2.95	2.67	0.49	5.34	0.14	8.37	100.15
		Sandstones*	18 (343)	79.24	0.28	6.61	1.54	0.75	0.04	1.67	1.89	0.61	3.21	0.08	4.28	100.20
	Urals	Shales	91	59.46	0.87	18.54	4.67	1.43	0.06	2.32	0.88	0.70	6.20	0.15	4.39	99.67
		Sandstones	239	88.49	0.21	4.84	1.22	0.72	0.04	0.51	0.53	0.35	1.78	0.06	1.08	99.83
	Siberian platform	Shales	31	57.58	1.33	20.71	3.71	2.43	0.03	1.76	0.66	0.44	3.79	0.06	7.76	100.26
		Sandstones	31	84.71	0.36	5.68	1.96	1.38	0.04	1.09	0.60	0.09	1.31	0.06	2.47	99.75
	Siberian platform framing	Shales	159	59.13	1.16	19.63	2.81	4.04	0.06	1.91	0.55	0.89	3.84	0.09	5.69	99.80
		Sandstones	110	83.44	0.36	6.64	1.09	2.24	0.05	0.92	0.65	0.79	1.49	0.10	1.95	99.72
	All regions	Shales	294	59.12	1.04	18.80	4.24	2.34	0.06	2.08	0.75	0.64	4.87	0.12	5.85	99.91
		Siltstones	142	67.55	0.81	14.18	2.52	3.56	0.05	1.91	0.55	1.33	3.63	0.11	3.05	99.25
		Sandstones	398	83.98	0.31	5.95	1.46	1.28	0.05	0.76	0.58	0.46	1.95	0.08	2.45	99.31
Vendian	Russian platform	Shales	667	58.46	0.96	18.71	4.01	3.64	0.09	2.24	0.64	0.94	3.96	0.13	5.71	99.49
		Shales*	32 (1063)	59.45	0.87	17.04	3.98	3.40	0.14	2.23	0.74	1.06	3.91	0.12	6.89	99.83
		Sandstones	369	83.10	0.34	7.38	1.24	1.30	0.05	0.65	0.71	0.70	2.17	0.07	1.95	99.66
	Urals	Shales	90	58.39	0.96	17.55	5.41	3.54	0.11	3.15	0.83	1.52	3.95	0.15	4.53	100.09
		Sandstones	125	82.13	0.38	7.08	1.74	1.77	0.07	1.08	0.71	1.38	1.28	0.07	1.77	99.46
	Siberian platform	Shales	34	57.61	0.93	18.12	3.05	2.07	0.06	3.17	1.00	0.46	5.72	0.08	6.69	98.96
		Sandstones	207	85.26	0.33	5.16	0.85	1.20	0.03	0.82	1.02	0.50	2.16	0.04	3.20	100.57
	Siberian platform framing	Sandstones	18	81.11	0.37	7.53	1.54	1.98	0.04	1.32	1.06	1.35	1.73	0.07	2.14	100.24
	All regions	Shales	823	58.19	0.93	17.95	3.76	2.80	0.09	2.86	0.87	0.82	4.83	0.12	6.20	99.42
		Siltstones	466	67.66	0.77	14.34	2.43	2.70	0.05	1.84	0.52	1.10	3.33	0.08	3.74	98.56
		Sandstones	719	82.91	0.36	6.79	1.35	1.57	0.05	0.97	0.88	0.99	1.84	0.07	2.27	100.05

* These data are cited from publications by Ronov and Kazakov (1983) and Ronov *et al.* (1990a). The number of specimens in the average samples is shown in parentheses; rocks with some carbonate admixtures are found among them.

Table 2. A list of the studied formations. The number of petrochemical analyses of terrigenous rocks is shown in parentheses. The number of analyses in each formation was not less than 10

Region / Age	Russian platform	Urals	Timan	Siberian platform	Siberian platform framing
	1	2	3	4	5
Vendian	Grushka (26) Mogilev (74) Yaryshev (112) Nagoryany (71) Danilovka (33) Zharnovka (28) Krushanovka (49) Studenitsa (53) Khmel'nitskii (37) Pletenev (25) Ust'-Pinega (250) Lyubim (261) Reshma (116) Lezhsk (23) Gdov (100) Kotlin (57) Voronka (42) Puman (17)	Suirovo (21) Uryuk (33) Basa (69) Kukkarauk (10) Zigan (23) Tanin (14) Garev (19) Koiva (11) Kernos (10) Staropechnaya (14) Chernyi Kamen' (22)	Lunvozh (38)	Dzherba (14) Moty Group (225)	
Upper Riphean	Pyaryayarvi (27) Palvinsk (14) Poropelon (23) Zemlepakhta (27)	Zil'merdak (222) Inzer (66) Uk (32) Tolparovo (32) Sablegorsk (10)	Novobobrovsk (20) Vizinga (25) An'yug (33) Klenovsk (24) Pokyusk (14)	Neryuen (16) Kandyk (12)	Goloustnaya (23) Uluntui (10) Kachergat (45) Ugakhan (14) Khomolkho (38) Aunakit (39) Vacha (23) Anangra (11) Neryuen (14) Potoskui (34) Strel'nye Gory (59)
Middle Riphean	Poles'e Group (53) Terskaya (26)	Mashak (67) Zigalga (17) Zigazino–Komarovo (72) Avzyan (77) Saitovo Group (27)		Totta (11)	Talyn (23) Totta (30) Valyukhta (16) Vitim (14) Slyudyanka (16) Sogdiondon (54) Konkudera (37) Bodaibokan (11)

Table 2. (Contd.)

Age	1	2	3	4	5
					Gorbilok (41) Uderei (121) Pogoryui (43) Ludovo (23) Gubino (12)
Lower Riphean		Ai (63) Satka (21) Bakal (29) Bol'shoi Inzer (62) Suran (32) Yusha (41)		Il'insk (12) Burdur (10) Labaztakh (18)	Trekhgorka (15) Dim (20) Chukcha (19) Khaiverga (11) Korda (123)

MAJOR TRENDS IN THE EVOLUTION OF TERRIGENOUS ROCKS IN THE NEOGAEA

Shales. One of the principal results of our research is the acquisition of information on the relative stability of the average composition of shales throughout the entire territory studied, from the Early Riphean through the Paleozoic. Most remarkable in this respect is the curve representing changes in the average K_2O content not exceeding the values of 4.6 - 5.2% during the Early Proterozoic to the Early Paleozoic. The curve has a sharp bend in the Middle-Late Paleozoic part, whereas the average K_2O content in the Mesozoic and Cenozoic clayey rocks on the Russian and North American platforms is not more than 2.8% (Fig. 1). Changes in the average value of the Al_2O_3/SiO_2 ratio are similar. The curve in Fig. 1 represents the cyclic variations of this parameter during the Late Precambrian and Paleozoic times and its sharp decrease in the Mesozoic and Cenozoic. The Fe_2O_3/FeO ratio in shales and sandstones is close to that in the Lower Proterozoic, Lower and Middle Riphean, and Lower Paleozoic deposits; it is higher in the Upper Riphean and much higher in the Mesozoic and Cenozoic (Figs. 1 and 2).

The histograms illustrating the distribution of petrogenic elements in terrigenous rocks also confirm that the composition of shales during the Late Precambrian was relatively stabile (Fig. 3). The distribution of SiO_2, Al_2O_3, and TiO_2 contents in a large number of the obtained histograms is close to bimodal: one of the maxima corresponds to the most common composition of shales and the other to that of sandstones (Sochava, 1986). As shown in Fig. 3, the modal values of the K_2O, SiO_2, Al_2O_3, and TiO_2 content in the Riphean and Vendian shales fall within a rather narrow range: 3 - 4%, 56 - 64%, 15 - 18%, and 0.65 - 1.0%, respectively. The position of the modes in these intervals for separate stratigraphic units of the Late Precambrian indicates cyclic changes rather than a monotonic evolution.

The obtained information introduces certain corrections into notions about the chemical composition of clayey rocks in the Late Precambrian and Phanerozoic and suggests that the turning-point in the history of the platform terrigenous sedimentation that falls on the Middle-Upper Paleozoic time ends the long period of relative stability in their average compositions.

The study of clayey rocks of that age on the North American platform revealed a considerable change in their mineral composition. Data collected by Weaver (1967) and generalized by Garrels and MacKenzie (1974) indicates that the stratigraphic level of the sharp change in the mineral composition of shales corresponds to the Carboniferous; that change is expressed in a decrease in the contents of illite from 80 to 40% and of chlorite from 10 to 5%, as compared to the underlying deposits, and an increase in smectites from 10 to 40% and in kaolinite from 10 to 40%. In the Cenozoic, the content of smectite rose to 60% and that of illite fell to 20%. The most important petrochemical characteristic of smectites, as compared to illite, is the noticeably lower content of K_2O and lower Al_2O_3/SiO_2 ratio.

While studying the mineral composition of shales in the Phanerozoic and Late Precambrian deposits of the Russian platform, Ronov and his co-authors (1990a) revealed a consecutive reduction in illite content from 40% in the Riphean–Lower Paleozoic to 10% in the Cenozoic and an increase of smectites (montmorillonite) from 4 - 5% to 30% in the respective periods of time. No uniform trend in variations in the kaolinite content in the shales were detected in this region in the Late Precambrian and Phanerozoic section in which kaolinite comprises 20% of the clayey minerals in both the Riphean and Cenozoic and two maxima in the Vendian (30%) and Mesozoic (36%). The trend of chlorite content variations is likewise not observed on the Russian platform (5% in the Riphean to Vendian and 7% in the Mesozoic).

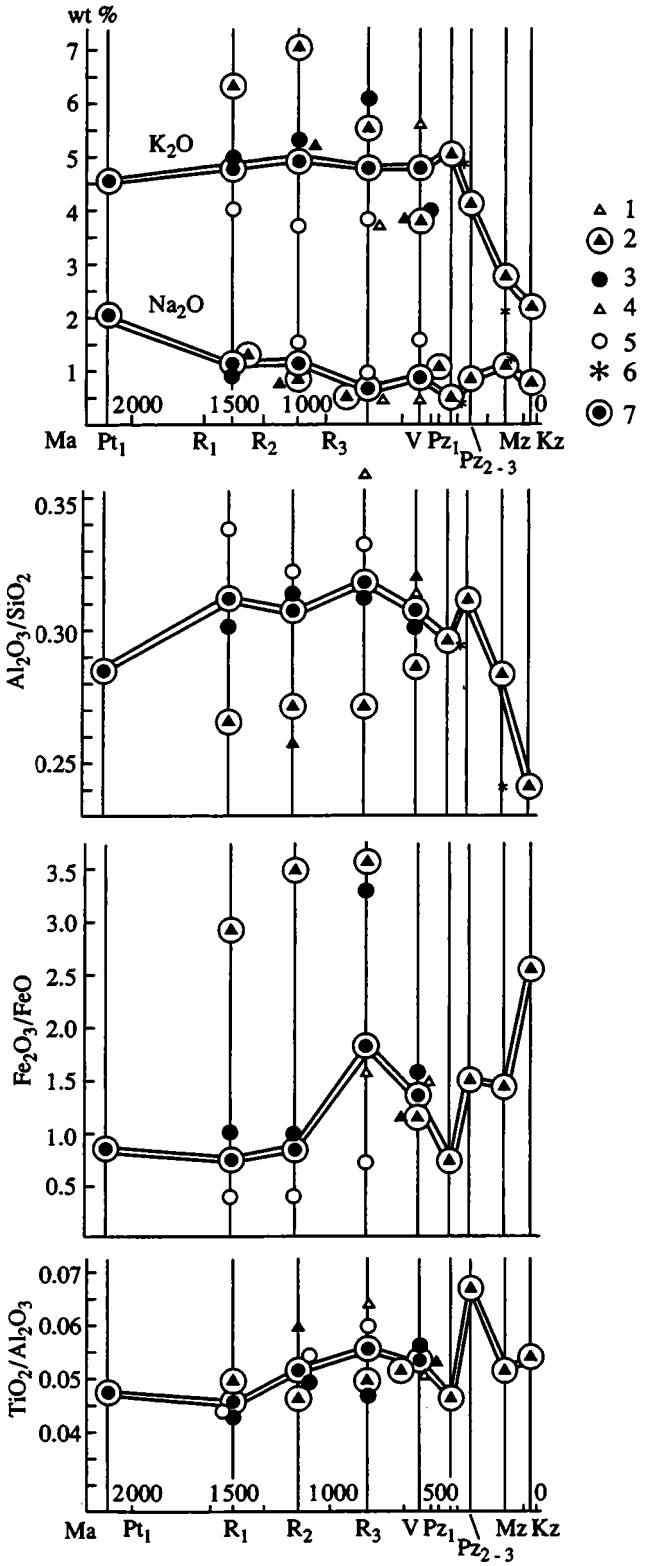

Fig. 1. Secular variations in the average composition of alkaline elements and in the values of certain petrochemical modules (wt %) in the Proterozoic and Phanerozoic shales. 1, 2 – Russian platform, based on our data (1), and on data by Vinogradov and Ronov (1956), Ronov *et al.* (1990a) (2); 3 – Urals fold; 4, 5 – Siberian platform (4) and its fold framing (5); 6 – North American platform (Ronov and Migdisov, 1970); 7 – average for all belt territories.

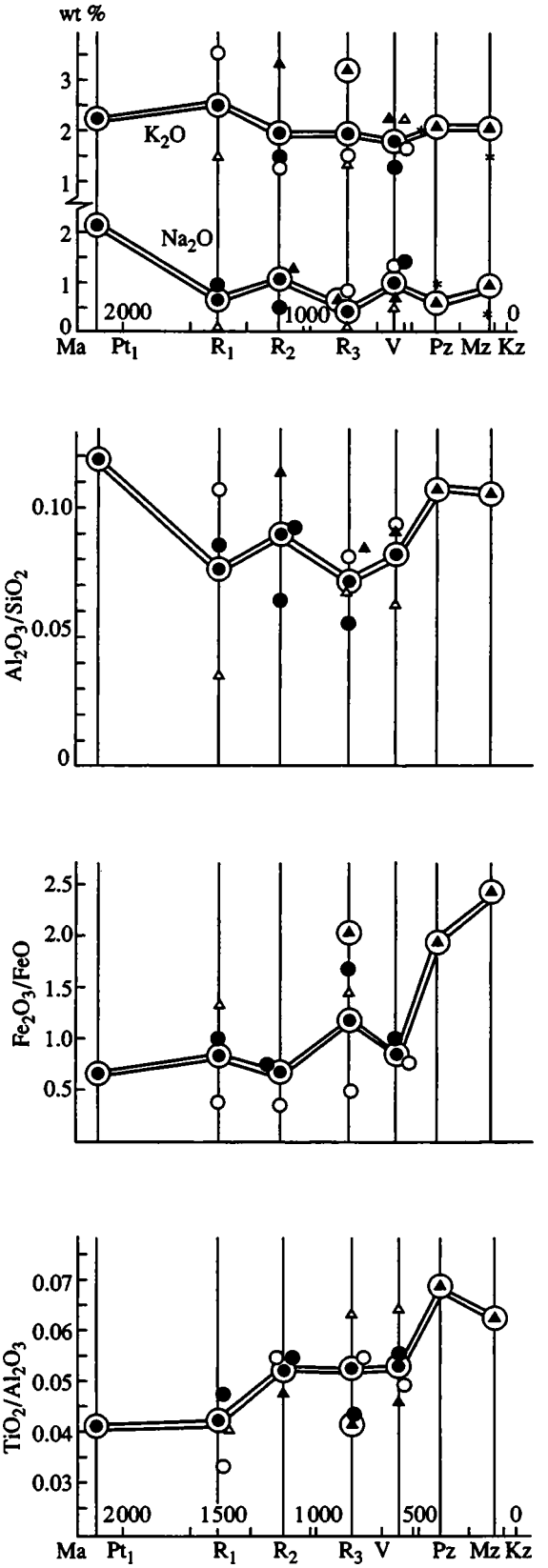

Fig. 2. Secular variations in the average composition of alkaline elements and in the values of certain petrochemical modules (wt %) in sandy rocks of the Proterozoic and Phanerozoic. For Legend see Figure 1.

The time interval of the change in the chemical and mineral composition of clayey rocks corresponded to one of the most significant events in the evolution of the biosphere, i.e., the advent of terrestrial vegetation (Reimer, 1972). As the evolution of the higher plants progressed, the influence of this factor on the weathering processes in the provenance gradually increased. The following circumstances conditioned the effect of terrestrial vegetation on the character of weathering in the provenance on the continents:

(1) The root system of plants is able to chemically affect the surrounding substratum, causing the breakdown of minerals necessary to produce the elements needed for plant feeding. The total length of the roots of a single plant can amount to several kilometers, while the pH of the environment may reach 2 in the immediate vicinity of the root filaments (Garrels and MacKenzie, 1974). The most important element for plant growth is potassium, which sometimes composes 10 - 15% of their cinder (Mats and Popov, 1975; Mikhailov, 1975; Golovenok, 1975; Sochava, 1979; Basu, 1981).

(2) The humic acids and CO_2, the products of organic matter decomposition, are important in the weathering process. It seems there are no reasons to infer that the Late Precambrian continents were lifeless. The productivity of the bacterial and lower algae assemblages, probably populating this ecological zone, could not reach, however, that of the higher plant assemblages. This statement is obviously supported by the appearance of coal-bearing layers only present in the Middle Paleozoic.

Ronov *et al.* (Ronov and Migdisov, 1970; Ronov *et al.*, 1990b) attribute the decrease in the content of K_2O in the shales from the Late Proterozoic through the Mesozoic–Cenozoic to the general change in the composition of rocks in the source areas of the continents, i.e., to the decreasing of the relative amount of granitoides and increase in that of sedimentary rocks. Considering that the K_2O content in the average composition of the Riphean–Lower Paleozoic terrigenous rocks is almost the same as that in the rocks of the shields (Ronov *et al.*, 1990b), and that a considerable removal of dissolved potassium has only occurred since the Middle Paleozoic, the effect of this factor could have only appeared at the terminal part of the Neogeicum (in the Mesozoic and Cenozoic). Apparently, this factor could only have enhanced the resulting effect – higher potassium mobility. Our curves, however, show no considerable changes in the K_2O content of the average compositions of sandy rocks in the Phanerozoic as compared with those in the Late Precambrian (Fig. 2). This is contrary to what might be expected, if essential changes were to have occurred in the average composition of rocks in the source areas.

The katagenetic transformation of mixed-layer clay minerals into hydromicas may also be another possible factor in the rise in potassium content in shales with age (Garrels and MacKenzie, 1974; and others). This model, however, does not explain the presence of highly potassic shales in certain facies, their considerable admixture of orthoclases (Ronov *et al.*, 1990a), and their frequent co-occurrence with monomictic quartz sandstones (see below). The last observation raises the problem concerning the source of potassium and aluminum necessary for the mentioned katagenetic transformations of the clay minerals. The casual nature of the coincidence of the upper limit of the supposed secondary process manifestation with the stratigraphic level corresponding to the time of the terrestrial plants advent, an important new factor in hypergenesis, also hardly seems probable.

The growth of the Fe_2O_3/FeO ratio in Phanerozoic clayey and sandy rocks can be attributed to their lower content of chlorites, biotite, and other silicate minerals containing ferrous iron. This, as well as the lower K_2O content in shales, was likely conditioned by the more complete disintegration of the primary minerals, the transition of iron into its reactive form, and its subsequent oxidation. The growth of the ratio, however, cannot be considered, as some authors have (Ronov *et al.*, 1990b), obvious evidence of a gradual increase in free oxygen content in the atmosphere through geologic history. On the other hand, the cyclic changes of O_2 content in the atmosphere, implied by the isotope data, i.e., a high content in the Late Riphean, a low content in the Vendian and Lower Paleozoic, and its general tendency to grow during the Phanerozoic (Sochava, 1992), correlate well with the Late Riphean maximum and the Vendian–Early Paleozoic minimum on our curves representing the changes in the Fe_2O_3/FeO ratio in the average compositions of both shales and sandstones.

The Na_2O content in the clayey and sandy rocks is controlled, to a large extent, by the presence of acid plagioclases (Ronov *et al.*, 1990a) and does not experience significant secular directional changes in the Late Precambrian through the Phanerozoic. The Na_2O content in the Lower Proterozoic clayey and especially in sandy rocks is much higher than in younger beds (Fig. 1). The higher sodium content in the Lower Proterozoic terrigenous rocks was caused, first, by the relatively higher content of this element in the Archean magmatic and metamorphic rocks of the source areas (Ronov and Migdisov, 1970; Sochava, 1986) and, second, by less Lower Proterozoic terrigenous deposit differentiation in the course of weathering and transportation. The latter conclusion is confirmed by a comparison of SiO_2 and Al_2O_3 distribution histograms in terrigenous deposits of the Lower and Upper Proterozoic. The modal values of contents of these elements in the most common types of sandstones and shales are much more similar on the histograms for the Lower Proterozoic than on those for the Riphean and Vendian (Fig. 3). The third reason for the specific nature of the Lower Proterozoic terrigenous deposits is the presence of units of tuff-sandstones and tuff-shales, which are the derivatives of alkaline volcanism of a specifically sodic nature. The Chitkanda and Aleksandrovskii formations of the Udokan depression (Sochava, 1986), or the Sariolian beds in the Imandra–Varzuga region (Melezhik and Pre-

dovskii, 1982), are examples of such deposits, with the respective average Na_2O content in shales being 2.5, 3.7, and 3.2%; the Na_2O contents in the sandstones of the same formations in the Udokan depression and in the Almalakhta Formation (Predovskii, 1980) of the Pechenga depression are 4.6, 3.7, and 3.2%, respectively.

Sandstones. The parts of SiO_2 histograms corresponding to the composition of the Upper and Lower Riphean sandy rocks represent the modal values of this oxide content within a range of 92 - 96% (Fig. 3), which corresponds in composition to monomictic quartz sandstones (Pettijohn *et al.*, 1972). A decrease in the value of the Al_2O_3/SiO_2 ratio in the riphean deposits as compared with the Lower Proterozoic sediments and its increase in the Paleozoic (Fig. 2) implies that the Late Precambrian was a time when highly mature sandy rocks in sediments were distributed extensively. The deposits of the second half of the Early Proterozoic (Sochava, 1979; 1986) and of the Early Paleozoic (Pettijohn *et al.*, 1972) likewise contain a large amount of quartz sandstones, e.g., the Segozero and Shoksha formations in Karelia (Sokolov *et al.*, 1970; Sochava, 1979).

Evidence indicating a distribution of less mature sandy deposits in the Phanerozoic than in the Late Precambrian leads us to the conclusion that neither the enhancement of chemical and biological weathering (Strakhov, 1962), nor the growing effect of the redeposition of sediments (Tsekhomskii and Karstens, 1982) controlled the formation of quartz sandstones. As intimated by Pettijohn *et al.* (1972), the principal factor in this process was the high degree of mechanical abrasion of sand grains, which is usually attained in two types of environments, i.e., agitated peritidal settings and, especially, in the eolian zones, where the abrasion of windblown sand grains is 100 - 1000 times more rapid than in subaquatic settings. There are no apparent reasons to suppose that there were principal differences in the distribution of peritidial zones in the Precambrian and in the Phanerozoic. On the other hand, the eolian reworking of terrigenous sediments should have been much more intensive in the Precambrian, because the appearance of terrestrial plants in the Paleozoic was a major impediment to this process.

Petrographic data provides further evidence that extensive eolian processes existed during the formation of the Precambrian monomictic quartz sandstones. On different stratigraphic levels and in various regions, medium sized grains, high sorting, well rounded grains, and quartz regenerated cement, i.e., a lack of silty-pelitic matrix, are their most typical properties. All of these features are typical of sandy material that underwent eolian reworking (Pettijohn *et al.*, 1972).

The more or less unidirectional growth of the TiO_2/Al_2O_3 ratio is one of the trends in the change of the average content of sandy rocks in the discussed regions. The mean value of this ratio in the Mesozoic and Cenozoic sandstones is higher than in the older beds despite the higher content of aluminum in the Mesozoic rocks. This evolutionary trend is more apparent in the sandy than in the clayey rocks (Figs. 1 and 2), thus implying the relation between it and the higher content of accessory titanium clastic minerals. This can be attributed to the repeated redeposition of terrigenous material during geologic history and to the gradual accumulation of it in titanomagnetite, ilmenite, sphene, and especially rutile and leucoxene; all these minerals are highly resistant to the destructive effect of chemical and physical agents (Ronov and Migdisov, 1970).

The larger role of the titanium-rich calc-alkaline and alkaline basic volcanies as the source of the initial material may be an alternative factor in the growth of the TiO_2/Al_2O_3 ratio in terrigenous rocks, especially, as we believe, on a regional scale. The Vendian shales of the Grushka, Mogilev, and Yaryshev formations in the L'vov–Kishinev depression can be cited as examples (Sochava *et al.*, 1992).

Siltstones. The studied sections contain an appreciably smaller amount of siltstones than shales and sandstones. The siltstones are terrigenous rocks of transitional granulometric composition with an intermediate average content of the most important petrogenic elements. By composition, the siltstones are closer to shales than to sandstones by virtue of their larger amount of clayey cement (Table 1). In the granulometric series of terrigenous rocks (sandstones–siltstones–shales), Na_2O shows a specific trend against the background of a successive reduction of SiO_2 and an increase in Al_2O_3, TiO_2, MgO, K_2O, Fe_2O_3, and FeO, i.e., the average content of Na_2O in siltstones is higher than in shales and sandstones (Table 1). This phenomenon can be explained by the mechanical crushing and attrition of feldspars and their accumulation in fine-grained terrigenous rocks. In this process, the smallest particles of plagioclases (the potential admixture in pelitic rocks), having a high specific surface, were mostly destroyed by the agents of chemical weathering. The fact that this had no effect on the potassium is due, first, to the higher stability of potassic fealdspars and mica and, second, to the reduction of sediments in the siliciclastic fraction accompanied by a simultaneous growth in the share of clay minerals, primarily hydromicas, which also have a high K_2O content.

Moreover, the average compositions of siltstones differ from those of shales and sandstones by a somewhat higher TiO_2/Al_2O_3 ratio value (Table 1), which was caused, perhaps, by an accumulation of mainly the heavy fraction of titanium-bearing minerals in them.

Sufficiently representative data about the average compositions of the Lower Proterozoic and Phanerozoic siltstones is not available. The average compositions of siltstones from discrete stratigraphic units of the Upper Proterozoic in the studied regions are characterized by practically the same SiO_2 and Al_2O_3 contents (Table 1). The K_2O contents are likewise similar in all the units except the Lower Riphean, where the higher potassium content characterizes the sandy rocks as well (Fig. 2), primarily the tuff-sandstones and tuff-siltstones of the Ust'-Il'ya, Dim, Trekhgorka, and Osor–Khayata formations (6 - 9% of the average composition).

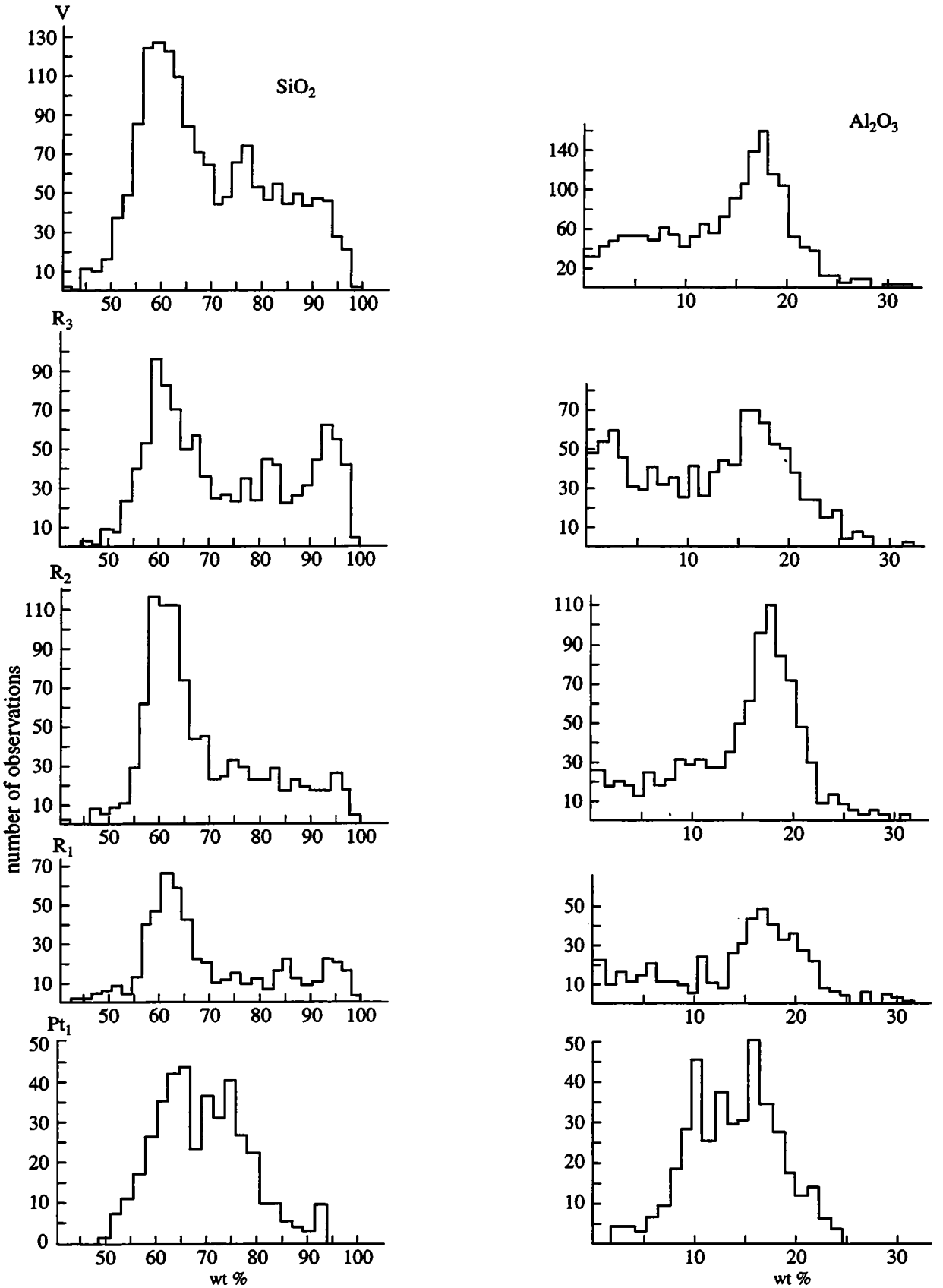

Fig. 3. Distribution histograms for SiO_2, Al_2O_3, K_2O, and TiO_2 in terrigenous rocks of the Late Precambrian of the Russian and Siberian platforms and of their fold framing. Pt_1 – the Udokan and Ugui groups in the western Aldan shield (Sochava, 1986).

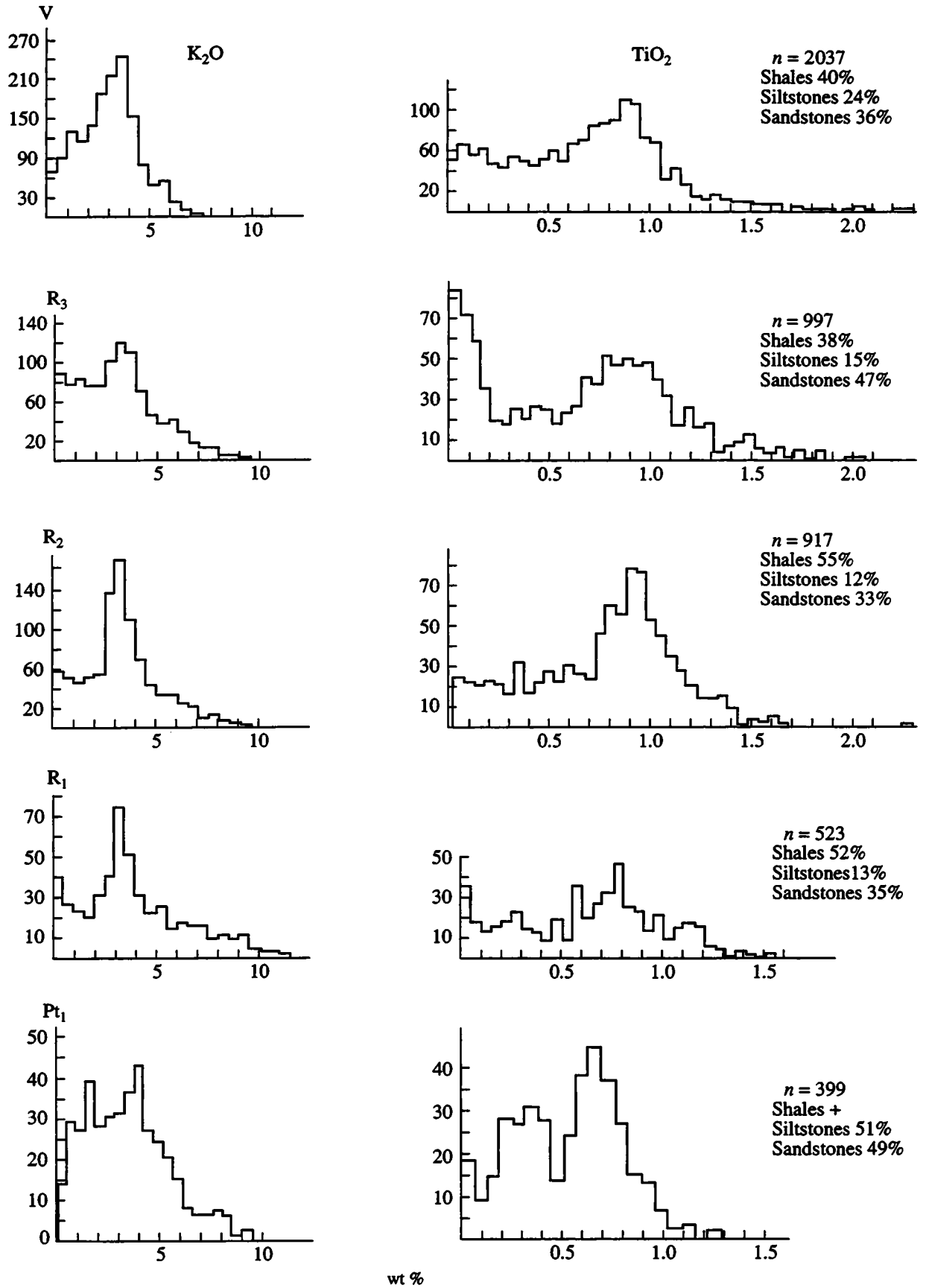
V
270
210
150
90
30
K_2O
5
10
TiO_2
n = 2037
Shales 40%
Siltstones 24%
Sandstones 36%
100
60
20
0.5
1.0
1.5
2.0
R_3
140
100
60
20
n = 997
Shales 38%
Siltstones 15%
Sandstones 47%
70
50
30
10
R_2
n = 917
Shales 55%
Siltstones 12%
Sandstones 33%
R_1
n = 523
Shales 52%
Siltstones13%
Sandstones 35%
Pt_1
50
40
0
n = 399
Shales +
Siltstones 51%
Sandstones 49%
wt %

Fig. 3. (Contd.).

THE PARAGENESES OF SANDY AND CLAYEY ROCKS AND THE PROBLEM OF HIGH-POTASSIUM SHALES

An analysis of paragenetic relations between certain types of clayey rocks and sandy rocks may shed light on the origin of some peculiar features in the composition of terrigenous associations. Such analysis (Fig. 4) allow us to identify rock associations with the least mature terrigenous material in the Upper Precambrian deposits of the studied regions. Typical examples of such associations are the greywacke beds of the Lonskii Formation on the Rybachii Peninsula (Table 3) and the two major types of associations with highly differentiated terrigenous rocks. In one of them, the oligomictic and monomictic quartz sandstones are associated with the high-aluminum low-potassium shales. The most typical examples are the Chukcha (Purpul), Voronka, and Neryuen formations (Table 3), where X-ray structural analysis revealed a high kaolinite contents (Golovenok, 1976; Pirrus, 1989). In another group of formations, the monomictic quartz sandstones are found in combination with highly potassic shales consisting up to 7% of K_2O in the average composition of formations and up to 10% in separate samples (the typical examples are the Sigalga and Tolparovo formations in the Urals). Shales of such a composition are also common in the Riphean deposits of the Russian platform; X-ray structural analysis shows a growth in their content of K_2O accompanied by an increase in potassic feldspar and, to a lesser extent, illite content (Ronov *et al.*, 1990). These two groups of associations of highly mature terrigenous rocks are probably the final products of the two major factors in the formation of the composition of terrigenous material, i.e., chemical weathering and the mechanical abrasion of particles. By eolian processes, the potassic feldspars with perfect soldering are attrited to fine-silt and pelitic grains, and through granulometric grading accumulate in clayey and silty rocks (Sochava, 1979).

Their preference of continental and coastal-marine environments is an important feature in the paleogeographic distribution of shales with anomalous potassium content (Sochava, 1979; Ronov *et al.*, 1990a), which implies short-distance transportation of clayey-silty particles, as shown by the comparison of compositions of the Riphean shales of the Russian and Siberian platforms (Fig. 1). The former are mainly coastal-continental and the latter of a deeper-water marine settings. This conclusion is confirmed by data on the extensive distribution of highly potassic shales in the Lower Proterozoic alluvial red-coloured formations (the Segozero and Shoksha formations of Karelia, the Sakukan Formation of the Udokan Ridge) (Sochava, 1979). All examples refer to high-potassium shales deposited as thin units in mainly sandy rocks. This phenomenon can be attributed to the aero- and hydrodynamic grading of silty-pelitic material, when the grains of potassic feldspars, owing to different physical properties and size, were transported shorter distances than the particles of the clay minerals proper.

According to Mats and Popov (1975), Mikhailov (1975), and Yudovich *et al.* (1991), the migration of potassium to the top of the weathering crusts and its subsequent fixation in the silicate minerals were important in the formation of high-potassium shales. As suggested by these authors, the relative inertness of potassium in the Precambrian weathering crusts, in contrast to Na, Ca, and Mg, and its accumulation with alumina were caused by the absence of higher terrestrial plants. Yudovich *et al.* (1991) presume that such processes were significant in the arid climate. The extensive amount of high-potassium shales in the Upper Precambrian deposits and their co-occurance with monomictic quartz sandstones cannot be accounted for by that process alone, because otherwise the latter would have brought about not only the formation of finely dispersed potassic minerals supplied to silty-pelitic sediments by granulometric grading, but also the regenerative growth of sand fragments of potassic feldspars size.

Shpunt (1987; Shpunt *et al.*, 1982) was the first to draw attention to the fact that the higher potassium content in the Upper Precambrian terrigenous rocks is also associated, to a certain extent, with specific features of rift volcanism. The basic alkaline volcanics, formed in the magma-generating zones of the deep mantle and characteristic of the Late Precambrian platform rifts, often have an anomalously high potassium content (over 10%) (Shpunt, 1987). The rock associations of the Ust'-Il'ya and Dim formations occupy a specific field (Fig. 4) among the Upper Precambrian terrigenous rocks. These associations compose the upper part of the Lower Riphean deposits framing the Anabar shield and the Uchur–Maya depression in eastern Siberia; they have the highest average K_2O content of all the shales (more than 8.5%) and a rather low SiO_2 content in sandstones. The petrography of these formations shows the presence of tuffs and tuff-sandstones, which also have an anomalously high K_2O content (Shpunt, 1987; Shpunt *et al.*, 1982; Semikhatov and Serebryakov, 1983) (Table 3).

As suggested by Shpunt (1987), the volcanogenic tephra material forms an essential part of the terrigenous deposits of the Late Precambrian platforms and, among other effects, accounts for the higher content of potassium in them. However, the isolated position of the field of obviously tuffogenic rocks with potassium specialization (Fig. 4) and a lack of transitional varieties between these rocks and the major field of compositions of rock associations on the diagram restrikt the application of the above model.

CYCLIC CHANGES IN THE COMPOSITION OF THE TERRIGENOUS ROCKS IN THE LATE PRECAMBRIAN

In addition to the general evolution trends discussed above, the curves in Figs. 1 and 2 demonstrate the small-scale cyclic changes in the composition of the Upper Precambrian terrigenous rocks. The petrochem-

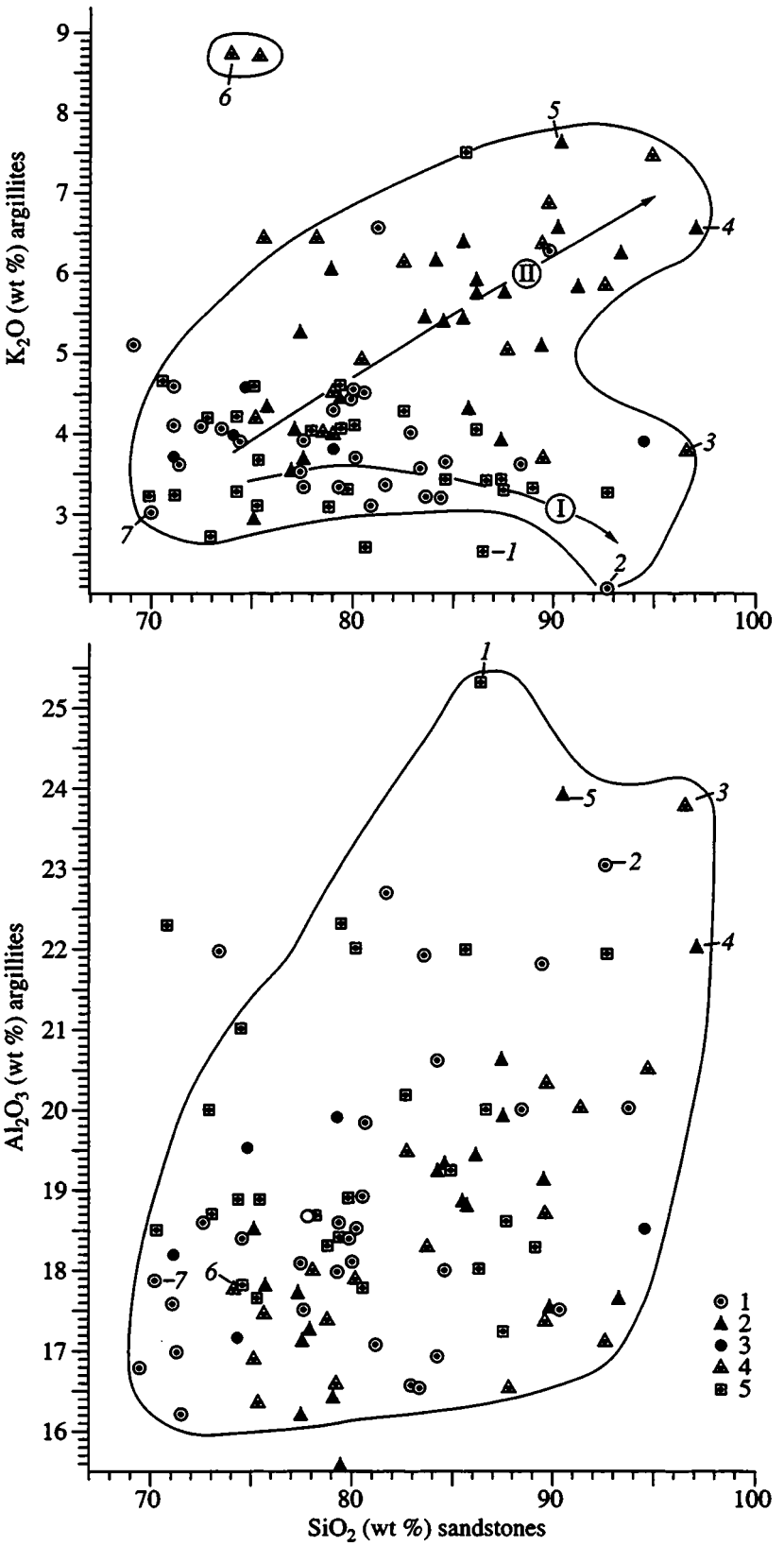

Fig. 4. Correlation of SiO_2 contents in the average compositions of sandstones and K_2O and Al_2O_3 content in shales of 133 separate formations of the Riphean and Vendian. I, II – trends in the changes of composition of terrigenous rocks under the effect of chemical weathering (I) and eolian processes (II). 1 – Russian platform, 2 – Urals, 3 – Timan, 4 – Siberian platform, and 5 – fold framing of the Siberian platform. Formations with maximum or minimum differentiation of compositions of terrigenous rocks: *1* – Chukcha, *2* – Voronka, *3* – Neryuen, *4* – Zigalga, *5* – Tolparovo, *6* – Dim, *7* – Lonskii (see Table 3).

Table 3. Average composition of shales and sandstones in the Late Precambrian formations with maximum or minimum differentiation of terrigenous material (see Fig. 4)

‹*	Formation	Region	Age	Rocks	Number of samples	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Ignition losses	Total
1	Chukcha	Patom Highland	R_1	Shales	8	56.72	1.12	25.29	2.87	6.21	0.15	1.18	0.42	0.38	2.52	0.11	2.57	99.54
				Sandstones	10	86.53	0.26	6.86	0.91	0.85	0.04	0.74	0.33	0.21	1.69	0.15	1.03	99.60
2	Voronka	Northwestern Moscow syneclise	V_2	Shales	8	57.98	1.25	23.04	5.88	0.69	0.03	0.58	0.16	0.13	2.08	0.05	7.69	99.56
				Sandstones	15	92.61	0.27	3.01	0.27	1.17	0.01	0.24	0.22	0.08	0.75	0.09	1.07	99.79
3	Neryuen	Uchur–Maya plate	R_3	Shales	14	58.27	1.61	23.78	3.21**		0.02	0.75	0.24	0.14	3.78	0.06	7.57	99.43
				Sandstones	2	96.71	0.09	0.76	0.81		0.01	0.10	0.37	0.01	0.05	0.02	0.72	99.65
4	Zigalga	Bashkir anticlinorium	R_2	Shales	2	58.29	0.92	21.99	3.64		0.08	1.33	0.19	0.11	6.47	0.10	5.83	98.95
				Sandstones	15	96.95	0.12	0.55	0.16	0.71	0.01	0.11	0.08	0.02	0.23	0.02	0.26	99.22
5	Tolparovo	Bashkir anticlinorium	R_3	Shales	3	56.37	1.25	23.88	4.12		0.13	1.34	0.36	0.71	7.63	0.15	4.17	100.11
				Sandstones	28	90.29	0.14	4.16	0.95	0.23	0.06	0.24	0.70	0.32	1.25	0.03	1.11	99.48
6	Dim	Yudoma–Maya depression	R_1	Shales	11	60.08	0.72	17.77	4.76		0.01	3.28	0.40	0.21	8.71	0.09	3.48	99.51
				Sandstones	8	74.06	0.37	11.31	2.51		0.01	1.69	0.84	0.62	6.10	0.09	2.09	99.51
7	Lonskii	Rybachii Peninsula	R - V	Shales	2	57.86	0.65	17.93	2.68	5.01	0.10	3.58	1.83	3.60	3.02	0.10	3.16	99.52
				Sandstones	8	70.13	0.42	13.56	0.90	3.11	0.05	1.69	2.29	3.77	2.09	0.14	1.34	99.49

Notes: *See Fig. 4.
**Fe_2O_3 + FeO.

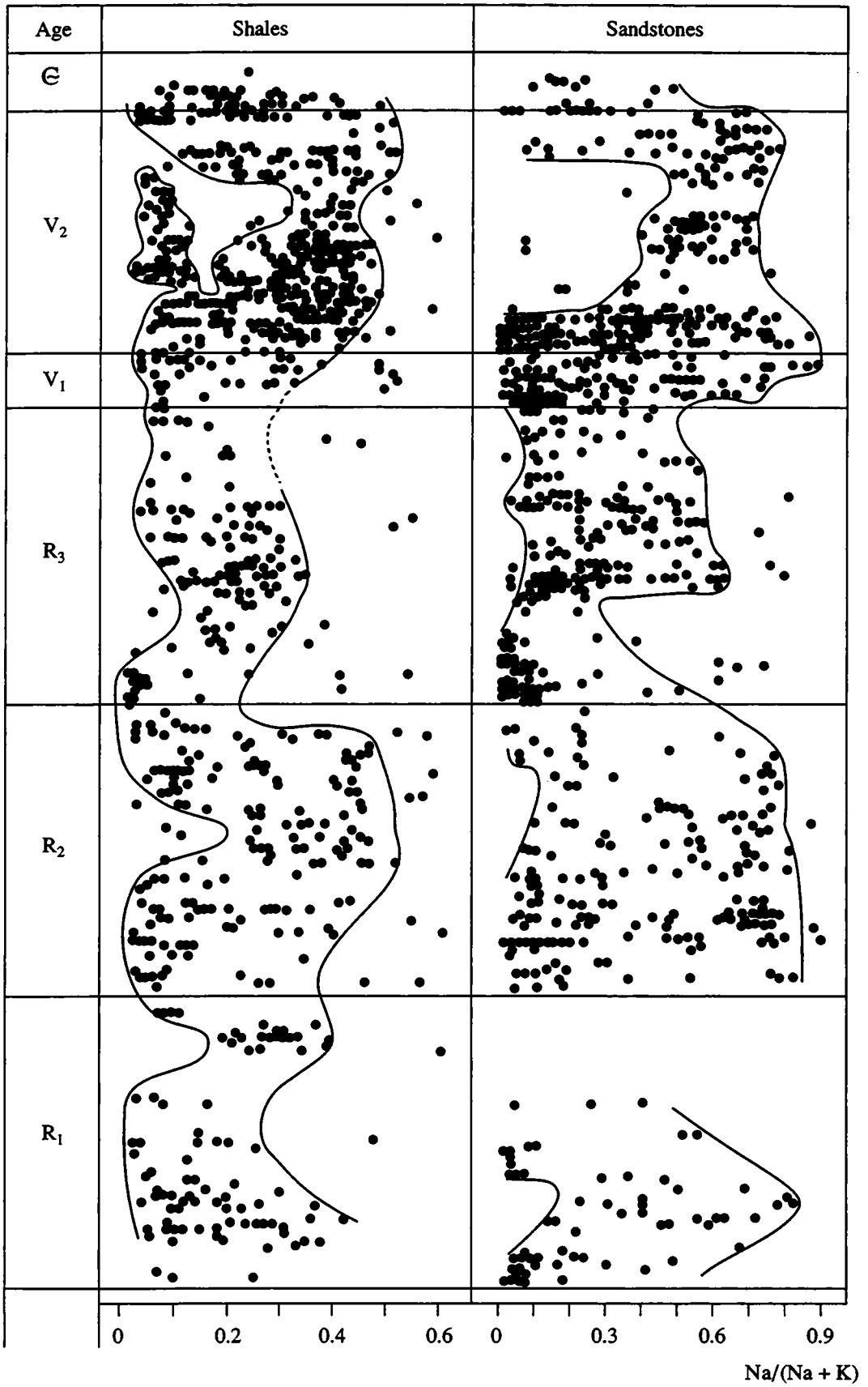

Fig. 5. Na/(Na + K) ratio values (atomic quantity) in the samples of the analyses of shales and sandstones of the Late Precambrian of the Russian and Siberian platforms and their fold framings.

ical data identifies two cycles of terrigenous sedimentation: the Lower-Middle Riphean and the Upper Riphean–Vendian. These cycles primarily reflect the tectonic history of the studied regions and are probably of greater importance because they coincide in time with the two units of the Precambrian stratigraphic scale suggested by the International Stratigraphic Commission, i.e., the Mesoproterozoic and the Neoproterozoic (Cowie *et al.*, 1984; Semikhatov, 1993). The initial elements of the cycles (the Lower and Upper Riphean) differ from the terminating elements (the Middle Riphean and the Vendian) in lower Al_2O_3/SiO_2 ratio values in sandy rocks and in the Na/(Na + K) ratio values in both sandstones and shales (Fig. 5). This cyclicity is also recorded on the oxide distribution histograms (Fig. 3). As noted above, the modal values of SiO_2 contents in the Lower and Upper Riphean sandstones fall in the 92 - 96% interval, and the lesser maxima in the 80 - 86% interval, whereas in the Middle Riphean and Vendian sandstones the contents of this oxide most frequently register in the 74 - 78% interval. Evidence of a higher maturity of the sandy material at the initial stages of the cycles characterizes them as stages of relative stability of tectonic regimes.

The terminating elements of the cycles, i.e., the Middle Riphean and Vendian deposits, contain rock associations of significantly different degrees of maturity. On the one hand, the deposits of these units have a higher absolute content of Na_2O (Figs. 1 and 2) and of the Na/(Na + K) module (Fig. 5) in sandstones and shales, which could be regarded as evidence of weak chemical weathering due to orogenic processes in the source areas or to active rifting. On the other hand, the shales of these epochs are highly aluminiferous, which is thought to indicate weathering of a higher intensity. The histogram modes of Al_2O_3 distribution representing the most common compositions of the Lower and Upper Riphean shales fall in the 15 - 17% interval and those of the Middle Riphean and Vendian, in the 17 - 18% interval. The corresponding modal values for TiO_2 are 0.75 - 0.80% and 0.85 - 0.95% (Fig. 3). According to Ronov *et al.* (1990a), the Vendian shales of the Russian platform differ from the Riphean ones by an appreciably higher content of kaolinite, 30% and 20%, respectively.

The data on the changes in the chemical composition of the Upper Precambrian carbonate rocks (Sochava and Podkovyrov, 1993) and on the isotope composition of carbon in these rocks (Sochava, 1992) lead to the conclusion that in the Vendian periods, and primarily in the Late Vendian, CO_2 was released into the atmosphere at a higher rate than in the Late Riphean, due to the general activization of the tectono-magmatic processes. Such an important change in the environment could not fail to cause higher intensity weathering in the source areas not affected by active tectonic processes. Among the Vendian deposits on the Russian platform, the formations with highly aluminiferous shales are quite common at the base of the Redkino Horizon (the Mogilev and Pletenev formations), or at the top of the Kotlino Horizon (the Voronka Formation). Moreover, the major part of the Kotlino Horizon in the southwestern area of the platform is composed of teleorogenic deposits with a low differentiation of terrigenous material and high sodium and magnesium contents (Sochava *et al.*, 1992). On the eastern framing of the platform (the Urals), the Redkino Horizon includes flyschoid greywacke associations in the Basa, Zigan, and Chernyi Kamen' formations.

The Vendian terrigenous deposits of the Siberian platform are also composed mostly of high-maturity associations with oligomictic and monomictic quartz sandstones (the Dzherba Formation in the south of the platform and the Moty Group of the Nepa–Botuoba anteclise). The Vendian deposits in the framing of the platform incorporate greywacke associations with a higher potassium content in sandstones, siltstones, and shales (the Ushakovka Formation in the Baikal area and the Dogaldyn and Iligir formations on the Baikal–Patom Highland).

Figure 5, besides large-scale cycles, also shows a minor level of activization of tectonic regimes, which is reflected in the growth of the Na/(Na + K) ratio in the Middle of the Upper Riphean. This event may indicate the stage of tectonic reorganization and activization corresponding in eastern Siberia to the base of the unit called the Baikalian; its isotopic age is about 850 Ma (Khomentovskii, 1990).

The results of the statistical interpretation of geochemical data, as shown in Figs. 1, 2, 3, and 5, give only a broad outline of the most general cyclic trends in the composition of the studied terrigenous rocks during the Late Precambrian. The validity of the plots, especially in Fig. 5, largely depends on the reliability and resolution of the stratigraphic scales used to correlate the sections. A more detailed analysis of the changes in the composition of the Upper Precambrian terrigenous rocks of the studied areas in the context of apparent regional tectonic and paleogeographic events is a task for future interpretations of our geochemical data.

CONCLUSION

The statistical analysis of the contents of petrogenic elements in the terrigenous deposits of the Russian and Siberian platforms and their fold framings suggests rather stable compositions of clayey and sandy rocks during the period of about two billion years of geologic time encompassing the late Early Proterozoic, the Late Proterozoic, and the Early Paleozoic. This inference corresponds to notions concerning the constant composition of the post-Archean upper continental crust derived from the composition of REE, i.e., the lack of long-term changes in Th/Sc, La/Sc, Eu/Eu*, and light/-heavy REE ratios in the sedimentary rocks (Taylor and McLennan, 1985).

The absence of higher plants on the Late Precambrian continents conditioned two major distinctions between the terrigenous sedimentation of this time and of the Late Phanerozoic. The first distinction was the

specific character of the weathering processes and the substantially lower mobility of potassium in the weathering crusts promoting the accumulation of potassic pelitic rocks of a predominantly hydromicaceous composition. The second difference was the extensive eolian reworking of terrigenous material and, as a consequence, a wider distribution of the monomictic quartz sands accompanied by siltstones and pelites complementarily enriched in finely grained potassic feldspars and micas. The active volcanism of potassic specialization, typical of the platform rift structures, had a certain, though apparently not primary, effect on the formation of high-potassium shales.

Our data gives new meaning to the representative data on the basic trends in the compositions of the Phanerozoic terrigenous rocks. These data imply a turning point in the evolution of terrigenous sedimentation in the Middle-Upper Paleozoic, related to the appearance of higher terrestrial plants as one of the most significant events in the evolution of the biosphere. The extent of the changes in the average compositions of terrigenous rocks elevates this event to a level commensurable, or even exceeding, another revolutionary highlight in the history of terrigenous rocks, i.e., the Archean–Proterozoic boundary, when the upper continental crust, saturated with potassium granitoids, evolved (Taylor and MacLennon, 1986; and others). In his works, Sochava (1986; Sochava and Mishin, 1986) analyzed the effect of the latter process on the petrochemical composition of terrigenous rocks of the Aldan shield.

During the Late Precambrian, the cyclicity of the tectono-magmatic processes was reflected in cyclic changes in the composition of terrigenous associations. During periods of higher tectono-magmatic activity, the orogenesis and rifting promoted the accumulation of low-maturity terrigenous rocks relatively rich in Na and Mg that are mobile in the weathering crusts, while the volcanic processes enriched them with mafic elements. On the other hand, in these epochs, the rate of CO_2 release into the atmosphere increased, causing higher surface temperatures and greater climate humidity. The combined effect of the rising pCO_2, temperature, and humidity led to the formation of the kaolinite weathering crusts in those parts of the source areas where the tectonic regime remained rather stable.

In the epochs of relatively passive endogenic processes, the CO_2 content in the atmosphere diminished, the climate became colder and even caused continental glaciation, the terrigenous sediments experienced greater mechanical destruction of particles by eolian reworking and formed associations with monomictic quartz sandstones and high-potassium shales. On the Russian and Siberian platforms and the surrounding territories, the regimes of terrigenous deposition of the first type were more typical of the Middle Riphean and Vendian, whereas the regimes of the second type were characteristic of the Early and Late Riphean. For the Late Riphean–Vendian cycle, this change in exogenic conditions is confirmed by data on changes in the isotope composition of sulfur, carbon, and strontium in the sedimentary rocks (Sochava, 1992) and by changes in the composition of carbonate rocks (Sochava and Podkovyrov, 1993).

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Devonian–Carboniferous Boundary Deposits in the Northern Timan–Pechora Province

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Abstract – The first zonation scheme for the Upper Famennian and Tournaisian shallow shelf deposits is suggested based upon previous bio- and lithostratigraphic studies and new data on spore and foraminifera distribution. This facilitated refinement of the Devonian–Carboniferous boundary position in the reference well "Nar'yan-Mar 1" located in the northern Timan–Pechora province, and correlation of boundary beds of this section with coeval deposits in southern areas of the province (Upper Pechora depression) and in other regions of the East-European platform.

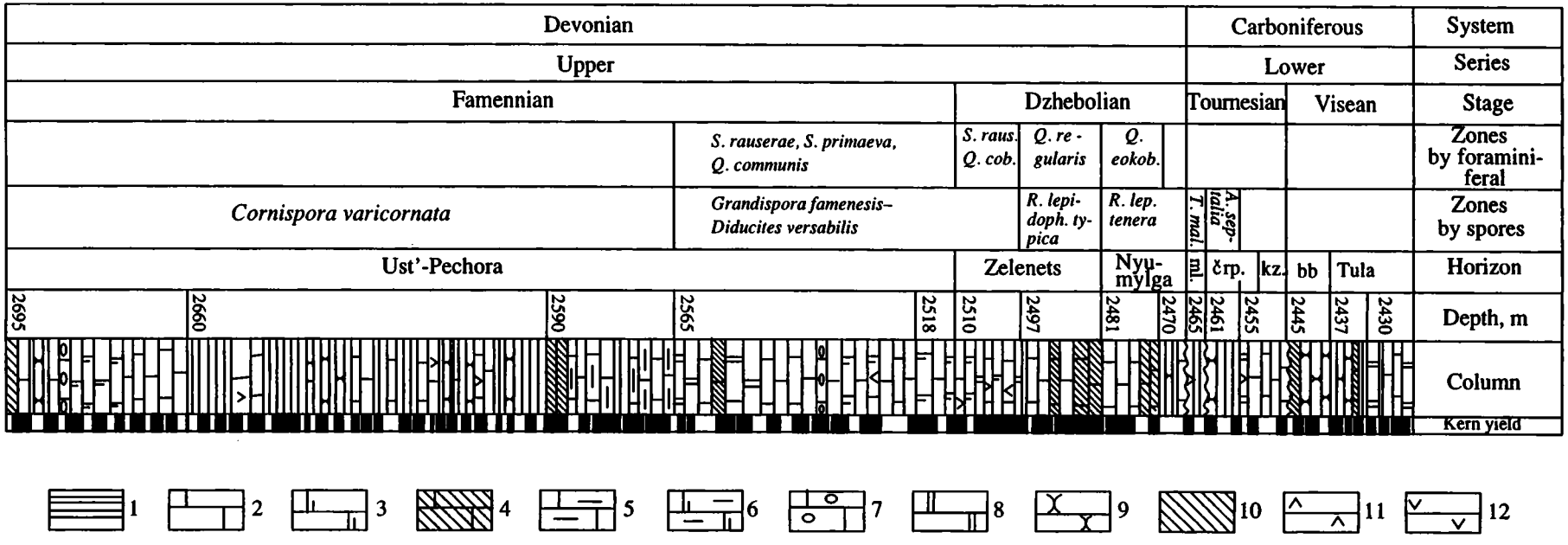
The Upper Devonian–Tournaisian deposits of the Timan–Pechora oil–gas field are known for bearing potential oil pools. Still, exploration works in northern areas of the province are of limited efficiency, because available stratigraphic schemes and correlations of producing and screening horizons are insufficiently accurate. That is why it is so necessary to study the detailed stratigraphy and correlation of the Upper Famennian and Tournaisian deposits, and to define more precisely the level of Devonian–Carboniferous boundary. In southern areas of the Timan–Pechora province, the recognition and biostratigraphic substantiation of regional Upper Famennian horizons are based upon sections consisting of basin and slope sedimentary facies deposited in uncompensated depressions (Durkina and Avkhimovich, 1988). In northern areas, where the Devonian–Carboniferous boundary deposits are represented by shallow shelf sediments, it is difficult to trace the same horizons, as reference sections of this facial zone have not been studied in detail. To remedy this we revised and investigated in more detail the biostratigraphy of the Nar'yan-Mar reference well, where the boundary deposits are well represented. As a result, we distinguished foraminiferal and spore zonation units of the Upper Famennian and Tournaisian intervals of the section, more accurately defined the boundary level between them, and detected correlative horizons in other sections of the East-European platform.

In the Nar'yan-Mar 1 section (the figure), the Devonian–Carboniferous boundary deposits have been subdivided (Kushnareva, 1977) into Ust'-Pechora, Zelenets, and Nyumylga horizons of the Famennian Stage of the Devonian, and higher, into the Malevka, Cherepet', and conventional Kizelovskii horizons of the Tournaisian Stage of the Lower Carboniferous, which in turn are transgressively overlain by the Visean sediments.

The Ust'-Pechora Horizon (an interval of 2510 - 2695 m) consists of carbonate and terrigeneous rocks. Its lower boundary coincides with the base of a sandy siltstone bed bearing the Lebedyan' spore assemblage. According to palynological data and changes in the composition of foraminiferal assemblages, the upper boundary was placed at a depth level of 2510 m. The horizon is subdivided into four members (Kushnareva, 1977; Kushnareva *et al.*, 1988).

The basal layer of the terrigeneous–carbonate Member I (interval 2660 - 2695 m) is composed of siltstone with interlayers of clay and limestone. Its upper part consists of normal and dolomitic limestones. Spore species comprise *Lophozonotriletes lebedianensis* Naum., *Cornispora monocornata* Naz., *Cyrtospora cristifera* (Lub.) Van der Zwan, and *Hymenozonotriletes lupinovitchi* Avch. of the *Cornispora varicornata* palynozone (determinations by L.G. Raskatova), which correlate to the Lebedyan' and Optukha horizons of the Famennian in the central provinces of the East European Platform.

Clay–carbonate Member II (interval 2590 - 2660 m) is rich in clay beds alternating with dolomitic and organic limestones, which contain rare sulphate inclusions and thin interlayers of sandstones. Organic remnants in the member are abundant. One limestone interlayer yielded the foraminiferal species *Bisphaera elegans* Viss. and *B. elegans* var. *subsphaerica* Viss. In Chizhova's opinion, the discovered ostracode assemblage of the member is similar to that from the Lebedyan' Horizon and Kiselevo-Nikol'skoe Beds of the central East European provinces.



The reference section of the Nar'yan-Mar I well.

1 – clay; 2 – limestone; 3 – dolomitic limestone; 4 – sandy limestone; 5 – clayey limestone; 6 – clayey dolomitic limestone; 7 – cloddy limestone; 8 – dolomite; 9 – sandstone; 10 – siltstone; 11 – anhydrite; 12 – gypsum.

Horizons: bb – Bobrovka; kz – Kizelovskii; črp – Cherepet'; ml – Malevka.

Biozonation units: *T. mal.* – *Tumulispora malevkensis* palynozone; *Q. kob.* – foraminiferal *Quasiendothyra kobeitusana* Zone; *Q. eokob.* – foraminiferal *Quasiendothyra eokobeitusana* Zone.

The rhythmic succession of Member III (interval 2555 - 2590 m) includes mainly siltstones, which grade upwards into clayey limestones (Durkina and Avkhimovich, 1988). Endothyroidal foraminifera of this member, represented by *Septaglomospiranella primaeva* (Raus.), *Rectoseptaglomospiranella* sp., *Septatournayella rauserae* Lip. forma *minima*, and *Quasiendothyra* (*Eoendothyra*) *communis* (Raus.) forma *minima*, occur in the interval of 2568.6 - 2572.6 m. The spore assemblage includes *Cornispora varicornata* Stapl. et Jans., *Grandispora famenensis* (Naum.) Streel. *G. cornuta* Higgs, *Endosporites golubinicus* (Naz.) Avch., *Hymenozonotriletes papulosus* Senn., *Lophozonotriletes curvatus* Naum., and *Diducites poljessicus* (Kedo) Van Veen. This assemblage is also referred to the *Cornispora varicornata* palynozone, and comparable with spore spectra in the Kiselevo-Nikol'skoe Beds and Optukha Horizon of the central East European provinces, or in the Shatilki Beds of the Upper Famennian Oressa Horizon in the Pripyat' depression (Avkhimovich, 1986).

Limestone Member IV (interval 2510 - 2555 m) is referred to the local foraminiferal zone described as beds with "rare specimens of *Septatournayella rauserae*, *Septaglomospiranella primaeva*, and *Quasiendothyra communis*." The member consists of organogenic, often dolomitic limestones containing rare anhydrite inclusions, and diverse, abundant fauna. Its foraminiferal assemblage is more rich in tournayellids, among which species of *Septatournayella rauserae* Lip. are represented by both "*minima*" and "*maxima*" forms. Such species as *Septaglomospiranella primaeva* (Raus.), *S. nana longa* Durk., and *Septabrunsiina minuta* f. *glomospiroides* Lip. are more common here than in the lower beds. Representatives of the *Quasiendothyra* group include small, primitive forms of *Quasiendothyra* (*Eoquasiendothyra*) *bella* N. Tschern., *Q.* (*Eoq.*) ex gr. *bella* N. Tschern., *Q.* (*Eoendothyra*) *communis* (Raus.) forma *minima*, *Q.* (*E.*) ex gr. *communis* (Raus.), and *Q.* (*E.*) *regularis* subsp. *eoregularis* Durk. The interval of 2510 - 2518 m near the top of Member IV is a level where new a *Quasiendothyra* group: *Q.* (*E.*) *communis*, *Q.* (*E.*) *communis infida* Durk., *Q.* (*E.*) *communis oldae* Durk., and *Q.* (*E.*) *eoregularis* Durk first occurs. Earlier (Durkina, 1975), this renewal stage in the foraminifera's evolution was thought to indicate the Devonian–Carboniferous boundary (at a depth level of 2518 m). Still more significant changes in the foraminifera's taxonomy occur higher, at a depth a 2510 m, where we now place the upper boundary of the Ust'-Pechora Horizon. The spore assemblage discovered from clay interlayers in limestones consists of *Endosporites golubinicus* (Naz.) Avch., *Grandispora famenensis* (Naum.) Streel, *G. cornuta* Higgs, *Knoxisporites dedaleus* (Naum.) Mor.-Ben., *Diducites poljessicus* (Kedo) Van Veen, *Convolutispora vermiformis* Hugh. et Playf., *Cyrtospora cristifera* (Lub.) Van der Zwan, and *Lophozonotriletes proscurrus* Kedo. The assemblage is referred to the lower part of the *Grandispora famenensis–Diducites versabilis* palynozone. It can be compared to assemblages from the Turgenevo Beds of the Famennian Plavsk Horizon in the East European platform and from the Osovets Beds of the Streshin Horizon in the Pripyat' depression (Avkhimovich, 1986).

Upward in the Nar'yan-Mar I (interval 2465 - 2510 m) section, there is a sequence of deposits corresponding to the Dzhebol Superhorizon of the Timan localities and divisible into the Zelenets and Nyumylga local horizons.

The Zelenets Horizon (the interval of 2481 - 2510 m) corresponds to two local foraminiferal zones: the lower *Septatournayella rauserae–Quasiendothyra communis minima* and upper *Q. regularis*.

The interval of the *Septatournayella rauserae–Quasiendothyra communis* Zone (2497 - 2510 m) is composed of detrital dolomitic limestones with gypsum and anhydrite inclusions, the top of which consists of dolomite bed. The most abundant forms of foraminifera are *Septatournayella* (mainly "*minima*," "*maxima*," and "*recta*" forms of *S. rauserae* Lip., and rarer *S. potensa* Durk.) and smaller *Quasiendothyra* species: *Q.* (*Eoquasiendothyra*) *bella* (N. Tschern.), *Q.* (*Eoq.*) ex gr. *bella* (N. Tschern.), *Q.* (*Eoendothyra*) *communis* (Raus.), *Q.* (*E.*) *communis* (Raus.) forma *minima*, *Q.* (*E.*) *communis* (Raus.) forma 1, and *Q.* (*E.*) *communis* (Raus.) forma 2. Other foraminifera of the beds include *Glomospirella elegans* Durk., *Quasiendothyra* (*E.*) *regularis* (Lip.), *Q.* (*E.*) *regularis* subsp. *densa* Durk., and *Septabrunsiina kingirica* Reitl species. This assemblage differs from that of *Q. communis venuata* Beds in the Upper Pechora depression in its lower diversity at the generic and specific levels, and in a higher proportion of *Septatournayella* forms. The spore species *Hymenozonotriletes papulosus* Senn., *Diducites commutatus* (Naum.) Avch. *Grandispora cornuta* Higgs, *Auroraspora macra* Sull., *Knoxisporites dedaleus* (Naum.) Mor.-Ben., *Lophozonotriletes proscurrus* Kedo, and *L. curvatus* Naum. determined in the lower part of the Zelenets Horizon are characteristic of the upper *Grandispora famenensis–Diductites versabilis* palynozone. This unit comprises the Kudeyarovka Beds of the Pavlovsk Horizon in the central East European platform and Lyuban' Beds of the Upper Famennian Streshin Horizon.

The upper part of the Zelenets Horizon (the *Quasiendothyra regularis* local zone, (the interval of 2481 - 2497 m) consists of organogenic detrital limestones. They contain abundant *Quasiendothyra* (*Eoendothyra*) *regularis regularis* (Lip.), *Q.* (*E.*) *regularis elata* Durk., *Q.* (*E.*) *regularis* (Raus.) forma *communiformis*, and *Q.* (*E.*) ex gr. *regularis* (Lip.) and such forms as *Q.* (*E.*) *communis communis* (Raus.) forma *simplex*, *Q.* (*E.*) *communis evoluta* Durk., *Q.* (*E.*) *communis* (Raus.) forma *chomatica*, *Q.* (*E.*) *communis praeturbida* Durk., *Q.* (*E.*) *communis infida* Durk., and *Q.* (*Eoquasiendothyra*) *bella* (N. Tschern.). The "*minima*," "*maxima*," and "*recta*" forms of *Septatournayella rauserae* Lip. are dominant among tournayellids, while *S. potensa* Durk. rarely occurs. Begining at the unit

base, representatives of *Septaglomospiranella primaeva* (Raus.), *Pseudoglomospira vytchegda* Durk., *Glomospira solaris* Durk., *Septabrunsiina oldae* Durk., *S. kingirica* Reitl., and *S. minuta* (Lip.) demonstrate the increasing abundance and subspecies diversity accompanied by scarce specimens of *Archaelagena petchorica* Grozd. et Leb. An associated spore assemblage includes specimens of *Retispora lepidophyta* (Kedo) Playf., *Diducites poljessicus* (Kedo) Van Veen, *Grandispora distinctus* (Naum.) Avch., *Auroraspora evanida* (Kedo) Avch., *Tumulispora malevekensis* (Kedo) Turnau, *Knoxisporites hederatus* (Isch.) Playf., and *Lophozonotriletes proscurrus* Kedo. The assemblage can be referred to the lower *Retispora lepidophyta typica* palynozone, and corresponds to the lower Ozerki Beds of the central East European platform, and to the Starobin Beds of the Upper Famennian Poles'e Horizon in the Pripyat' depression.

The Nyumylga Horizon (interval 2465 - 2481 m) is the terminal one in the Upper Famennian sequence. It consists of lower carbonate and upper terrigeneous members. The lower member, which consist of organic detrital and silty limestones (interval 2475 - 2481 m), corresponds to the stratigraphic range of the *Quasiendothyra eokobeitusana* local zone. Here, the most significant foraminifera forms are *Quasiendothyra* (*Quasiendothyra*) *eokobeitusana* Durk. and *Q.* (*E.*) ex gr. *eokobeitusana* Durk., associated with the increasing amount of *Q.* (*Endothyra*) *communis* and *Q.* (*E.*) *regularis*. The interval under consideration such new forms as *Q.* (*E.*) *petchorica* Durk., *Q.* (*E.*) *regularis conferta* Durk., *Q.* (*E.*) *regularis* (Raus.) forma *endothyroides*, and rare *Q* (*Eoquasiendothyra*) *bella* N. Tschern first occur. *Septatournayella rauserae* Lip., *S. potensa* Durk., and *Tournayella* sp. still exist in abundance among tournayellids, whereas such forms as *Septabrunsiina minuta* (Lip.), *S. kingirica* Reitl., *Glomospirella*? *irregularis* (Moell.), *Glomospiranella*? *djebolica* Durk., and *Septaglomospiranella* ex gr. *primaeva* (Raus.) dominate among the septabrunsiids. Species of *Archaelagena petchorica* Grozd. et Leb. are more common here than in the underlying deposits. The spore assemblage of the member is represented by specimens of *Retispora lepidophyta* (Kedo) Playf. var. *tenera* Kedo, *R. lepidophyta* (Kedo) Playf., *Knoxisporites literatus* (Waltz) Playf., *Dictyotriletes scrobiculatus* Kedo, *Diducites poljessicus* (Kedo) Van Veen, *Verrucosisporites mesogrumosus* (Kedo) Byvsch., and *Convolutispora vermiformis* Hugh. et Playf. The assemblage is referred to the *Retispora Lepidophyta tenera* palynosone distinguished in the Upper Ozerki Horizon of the central East European platform.

The Upper member of clays with thin sandstone interlayers (interval 2465 - 2470 m) is barren of foraminifers, yet can be conventionally attributed to the *Quasiendothyra kobeitusana kobeitusana* Zone of the Nyumylga Horizon, because this level in the Pechora–Kozhva sections (wells 70 and 84 of Kozhva–Kamenka locality; well 174 of West Soplyas locality) is rich in *Quasiendothyra kobeitusana* Raus. The dominant spore species recovered from the interval of 2468.4 - 2472 m, are represented by *Retispora lepidophyta* (Kedo) Playf. var. *tenera* Kedo, *R. lepidophyta* (Kedo) Playf., *R. lepidophyta* (Kedo) Playf. var. *minor* Kedo, *Tumulispora malevkensis* (Kedo) Turnau, *T. rarituberculata* (Lub.) Pot., and *Auroraspora macra* Sull. This assemblage correlates to the assemblage from the upper part of the *Retispora lepidophyta tenera* palynozone characteristic of the Khovan Horizon in the central platform provinces and the lower Borovoe Beds of the Upper Famennian Poles'e Horizon in the Pripyat' depression.

The paleontological characteristics of the Tournaisian deposits recovered at the Nar'yan-Mar I well (the interval of 2445 - 2465 m) are available only for their Malevka and Cherepet' horizons. The Malevka Horizon (the interval of 2461 - 2465 m) consists of alternating clay and siltstone beds with two thin sandstone interlayers. The rocks contain a spore assemblage of *Tumulispora malevkensis* (Kedo) Turnau, *T. rarituberculata* (Lub.) Pot., *Lophozonotriletes excisus* Naum., *Convolutispora major* (Kedo) Turnau, *Grandispora echinata* Hacq., *Bascadaspora mischkinensis* (Byvsch.), *Corbulispora cancellata* (Waltz) Bhar. et Venk., and *Retusotriletes incohatus* Sull. The assemblage corresponds to the *Tumulispora malevkensis* palynozone, which is characteristic of the Malevka Horizon of the Tournaisian Stage throughout the East-European platform. The overlying member (interval 2455 - 2461 m) consists of clays bearing siltstone interlayers in its upper part and sandstone beds at the base. The rocks contain spores of *Apiculiretusispora septalia* (Jusch.) Byvsch., *A. rarispinosa* (Jusch.) Byvsch., *Vallatisporites dictyopterus* (Waltz.) Byvsch. et N. Umn., *V. verrucosa* Hacq., *V. genuinus* (Jusch.) Byvsch., *Cymbosporites varius* Byvsch., *Tumulispora rarituberculata* (Lub.) Pot., *T. malevkensis* (Kedo) Turnau, *Lophozonotriletes excisus* Naum., and *Umbonatisporites regidesetosus* (Kedo) Byvsch. et Streel, all belonging to the *Apiculiretusispora septalia* palynozone typical of the lower Cherepet' subhorizon. Above it, the Nar'yan-Mar section includes a carbonate member (interval 2445 - 2455 m) of lower dolomites and upper algae limestones. The latters contain the rare foraminifera species *Septaglomospiranella* sp., smaller *Tournayella*? sp., *Endothyra* (*Planoendothyra*) cf. *rotayi* (Dain.), and *Latiendothyra* sp. Available *Latiendothyra* and *Planoendothyra* forms tentatively suggest that their host rocks correlate to the Cherepet'–Kizelovskii horizons.

The studied succession of Upper Famennian and Tounaisian assemblages of foraminiferas and spores from the Nar'yan-Mar section lacks some fossil groups distinguished in more complete sections of southern localities of the province (Durkina and Avkhimovich, 1988). This shows that there are stratigraphic hiatuses in the section, first between the Famennian and Tournaisian stages (at the base of the Malevka Horizon), where the upper part of the Nyumylga Horizon and entire Sotchemshor Horizon of the Tournaisian seem

absent, and second, between the Malevka and Cherepet' horizons of the Tournaisian, where deposits of the Upa Horizon are missing. The Tournaisian and Visean stages are also separated by a stratigraphic hiatus comprising intervals of the Kos'va and Radaevskaya horizons of the Lower Visean.

The Visean deposits transgressively overlying Tournaisian sediments are subdivided into the terrigeneous Bobrovka and terrigeneous–carbonate Tula horizons. The Bobrovka Horizon (interval 2437 - 2445 m) consists of siltstones and sandstones bearing spores of *Monilospora variomarginata* (Playf.) Byvsch., *Cingulizonates luminosus* Jusch. et N. Umn., *Densosporites triangulatus* (Byvsch.) Byvsch., *D. goniacanthus* (Waltz) Byvsch., *Knoxisporites literatus* (Waltz) Playf., and *Euryzonotriletes ciliato-marginatus* (Waltz) Byvsch. The assemblage is similar to that from the lower part of the Bobrovka Horizon in the central East European provinces.

Lithologically, the Tula Horizon (2421 - 2437 m) can be divided into lower terrigeneous and upper carbonate parts. The lower one (2430 - 2437 m) consists of interlayering clays, clayey siltstones, and sandstones, and has a limestone bed at the top. Foraminiferas *Globoendothyra elegans* Durk., *Endothyra* aff. *posneri* Gan., *E. cara* Schlyk., and *Omphalotis* ex gr. *omphalota* Raus. et Reitl have been detected in the limestone. Associated spores include *Cingulizonates bialatus* (Waltz) Kedo, *Densosporites gibberosus* (Naum. et Byvsch.) Byvsch., *Lycospora pusilla* Ibr., *Schulzospora campyloptera* (Waltz) H.S.M., *Trilobozonotriletes incisotrilobus* Naum. et Isch., *Auroraspora rugosiuscula* (Kedo) Byvsch., and *Lophotriletes parviverrucosus* (Waltz) Kedo, indicating the Tula Horizon age of the host deposits.

The upper part of the horizon (2421 - 2430 m) consists of limestones with dolomite interbeds, and contains the following foraminiferal species: *Earlandia vulgaris* Raus. et Reitl., *Archaediscus moelleri* Raus., *Endothyra prisca* Raus. et Reitl., *Globoendothyra globulus* Eichw., *G. ishimica* Raus., *Eostaffella proikensis* Raus., *Endothyra similis* Raus. et Reitl., and *Omphalotis omphalota* Raus. et Reitl.

The results obtained demonstrate that in the reference section Nar'yan-Mar I containing shallow shelf sediments, the succession of biostratigraphic units in the Devonian–Carboniferous boundary deposits is very similar to that recognized in carbonate–terrigeneous basin deposits of southern Upper Pechora depression (Durkina and Avkhimovich, 1988).

The *Cornispora varicornata* palynozone characteristic of the lower part of the Ust'-Pechora Horizon of the Upper Famennian is distinguishable in both regions under comparison. The local foraminiferal zone, or beds with rare specimens of *Septatournayella rauserae*, *Septaglomospiranella primaeva*, and *Quasiendothyra communis* f. *minima* (the upper part of Ust'-Pechora Horizon), correspond to the *Septaglomospiranella primaeva–Quasiendothyra bella–Q. communis evoluta* Zone of the Upper Pechora depression. The other local zone, or *Septatournayella rauserae–Quasiendothyra communis* Beds, distinguished as the lower part of the Zelenets Horizon in the Nar'yan-Mar section, correlates to the coeval *Quasiendothyra communis venusta* local zone of the Upper Pechora region. In both the northwestern (Nar'yan-Mar locality) and southeastern (Upper Pechora depression) parts of the province, upper strata of the Zelenets Horizon together with lower beds of the Nyumylga Horizon correspond to the foraminiferal *Quasiendothyra regularis* and *Q. eokobeitusana* local zones and to *Retispora lepidophyta typica* and *R. lepidophyta tenera* palynozones. In contrast to the Upper Pechora depression, the *Quasiendothyra kobeitusana* local zone of the Upper Nyumylga Subhorizon has not been distinguished in the northern Timan–Pechora region. Here, this interval was dated by spores assemblages. The *Quasiendothyra dentata–Q. kobeitusana* (the uppermost part of Nyumylga Horizon) and *Septatournayella njumylga–S. potensa* (the Sotchemshor Horizon) local zones of the more representative Upper Pechora sections are missing in the Nar'yan-Mar locality, which indicates a stratigraphic hiatus in its sequence. Still, the Tounaisian deposits of this reference section yielded, like their counterparts in Upper Pechora depression, spores of *Tumulispora malevkensis* and *Apiculiretusispora septalia* palynozones characteristic of the Malevka and Cherepet' horizons.

According to new results on the Nar'yan-Mar I reference section and available data on Upper Pechora localities (Durkina, 1959, 1972, 1975, 1984, 1988; Durkina and Avkhimovich, 1988), the most evolved forms of quasiendothyrids and septatournayellids occur within an interval from the base of the *Septatournayella rauserae–Quasiendothyra communis* Beds up to the roof of the *Q. dentata–Q. kobeitusana grandis* Zone, i.e., within the Dzhebol Superhorizon. The same interval corresponds to the stage of the first and then more abundant occurrences of *Retispora lepidophyta* specimens. Thus, the determination of boundaries and the stratigraphic range of the Dzhebol Superhorizon is essential to the task of solving one of the most complicated problems concerning the boundary position between the Devonian and Carboniferous systems in the Timan–Pechora region.

Reviewer V.V. Menner

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Evolution of the biosphere

Biostratigraphy and Biogeography of the Early Permian in the Southeastern Pamirs

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Abstract – The described sections of the Lower Permian Tashkazyk Formation of the southeastern Pamirs were analyzed for faunal assemblages of Brachiopoda, Ammonoidea, and other groups of marine invertebrates for a detailed correlation with sequences in adjacent regions. It is concluded that from a paleogeographical standpoint the southeastern Pamirs was a province of the peri-Gondwanian margin of the Paleotethys.

In the Murgab–Aksu structural zone of the southeastern Pamirs, the Permian deposits were widespread and distinctly divisible into two parts. The lower Bazardara Series generally consists of terrigeneous rocks and composes the main part of the Paleozoic sequence. It is up to 2000 m thick, though the basal horizons are unknown. Two units, the Uruzbulak and Tashkazyk formations, were recognized in the Bazardara Group. The lower Uruzbulak Formation consists of feldspar–quartz and graywacke sandstones and siltstones. The upper Tashkazyk Formation includes clayey clastic rocks of a mixed composition and has a flyschoid structure. In Novikov's (1976; 1979) opinion, the boundary between formations coincides with the regional erosion surface marked by boulders and lumps, which were produced as a result of disintegration and a sliding of coeval and older rocks.

In the distribution area of the Bazardara deposits, there are three basic types of sections formed under different structural and facial conditions (Novikov, 1979). The North Alichur and Karabeles section types occur in the western, northern (except the area near the town of Murgab), and eastern parts of the region. These sections are of considerable thickness, e.g., the Tashkazyk Formation is 700 to 980 m thick. The reduced and incomplete sections of the third Kastanat–Djilga type are confined to a syndepositional uplift that was located in the central and southeastern parts of the region (Fig. 1). The Uruzbulak Formation occupies an insignificant part of these sections (probably because they are poorly exposed). The Tashkazyk Formation is also peculiar here; it has a reduced (300 - 500 m) thickness, mainly consists of fine-grained and clayey rocks with a higher proportion of calcareous components, and bears abundant and diverse organic remains.

STRATIGRAPHY OF THE TASHKAZYK FORMATION

According to Novikov's descriptions, the Bazardara Group is most completely represented in two sections of the Kastanat–Djilga type: along the right upper tributaries of the Kastanat–Djilga River and on the southern slope of a nearby peak with a height of 4782.4 m, where the following beds are exposed (Fig. 2):

Uruzbulak Formation

(1) Black cleavable claystone with interlayers of dark gray lumpy and clayey, sometimes calcareous siltstones. Both rocks contain white mica flakes as admixture. The apparent thickness is about 100 m.

(2) Grey greywacke sandstone of variable grain size bearing plant detritus and indeterminable remains of brachiopods, crinoids, and bryozoans. The thickness is about 10 m. Above, there is an alternation of black claystones, brownish-grey faintly laminated sandstones, and sandy limestones overloaded with dismembered variably oriented valves of bivalve mollusks *Oriocrassatella* aff. *stokesi* Etheridge.[1] It is 21 m thick.

[1] Determinations by: T.A. Grunt (Paleont. Inst., RAS) for brachiopods, L.V. Kushnar' (Len. Gos. Univ.) for bivalves, M.V. Bogoslovskaya (Paleont. Inst., RAS) for ammonoids, G.A. Stukalina (All-Russia Geol. Inst.) for crinoids, R.V. Gorjunova (Paleont. Inst., RAS) for bryozoans, and T.G. Il'ina (Paleont. Inst., RAS) for corals.

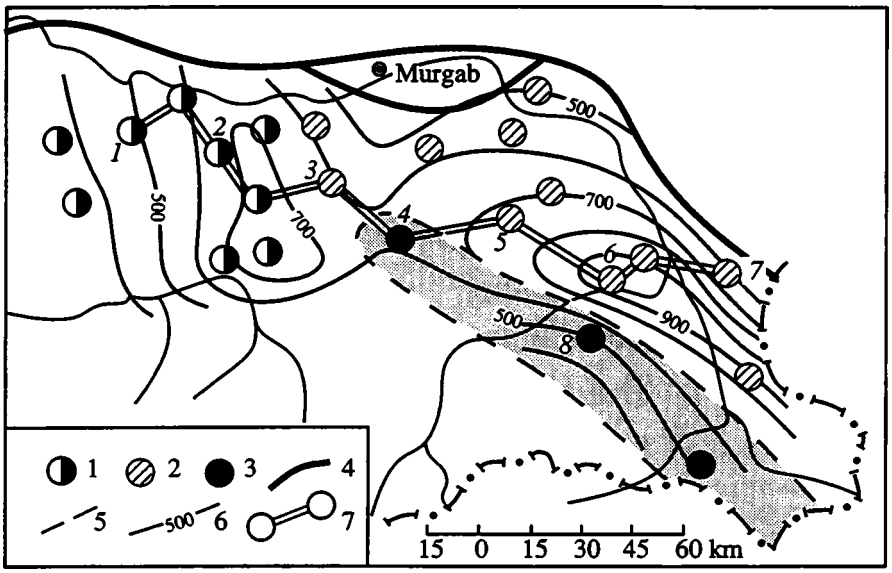

Fig. 1. Scheme of the Bazardara Group section localities in the Murgab–Aksu structural zone.

1 - 3 – section types: 1 – North Alichur; 2 – Karabeles, 3 – Kastanat–Djilga; 4 – tectonic boundaries; 5 – boundaries of synsedimentary uplift; 6 – Tashkazyk Formation isopach in meters; 7 – line of the lithostratigraphic profile.

Localities indicated by numbers in the scheme: *1* – North Bazardara; *2* – North Ak-Arkhar; *3* – Chakobai; *4* – Kurteke; *5* – Zor-Akbura; *6* – Sul'-Istyk; *7* – Dunkel'-Dyk; *8* – Kastanat–Djilga.

Tashkazyk Formation

(3) Brownish-grey (as dark as black), organic-detrital, sandy limestones bearing pebbles of quartz and siliceous rocks along with abundant bivalves, gastropods, brachiopods, corals, crinoids, and bryozoans. The limestones and associated limy sandstones form lensing interbeds varying in thickness from 0.4 - 0.6 to 20 - 25 m. Inside the limy claystone, there are lumps of irregular shape and rounded boulders (up to 4 - 7 m in diameter) of limestones similar in composition to the preceding rock type. These bear the fossil ammonoids *Metapronorites* sp. and larger *Conularia* sp. along with the bryozoans *Polyporella decora* Gorjunova and *P. visenda* Gorjunova, the crinoids *Pamirocrinus pamiricus* Stukalina, the bivalves *Pseudomyalina* sp., and the brachiopods *Permochonetes pamiricus* Afanasjeva, *Kitakamithyris petaliformis* Pavlova, *Cancrinella* ex gr. *farleyensis* (Etheridge et Dun), *Notospirifer* sp. nov., and *Neospirifer* ex gr. *joharensis* Diener. The thickness is 40 - 60 m. All the rocks of the bed are similar in composition, being to a certain degree genetically related to the underlying greywacke sandstone of the Uruzbulak Formation. Their clastic fraction generally includes grains of quartz, feldspar, and disintegrated volcanic glass or rocks. Usually, there is an admixture of dolomite (up to 25%) in the calcite matrix of calcareous rocks and sandstones. The complicated structure of the bed, its variable thickness, and the available boulders and lumps indicate intraformational erosion of deposits.

(4) Frequent flyschoid intercalation of black lamellar claystones with brownish-grey clayey sandstones and siltstones. The clay components are chlorite and hydromica. The bed base is marked by tracks of limivorous organisms and mechanoglyphs. It is 9 to 10 m thick.

(5) Black claystone containing interbeds of yellowish-grey calcareous claystones and lenses of limestones. Brownish-grey limy-clayey sandstones near the top of the bed include small bivalves and poorly preserved gastropods. It is 25 to 30 m thick.

(6) Claystones irregularly alternating with brownish-black clayey siltstones and rare discontinuous interbeds of clayey limestones bearing oval concretions of calcareous siltstones. The rock contains organic detritus, crinoid remnants, and the bryozoan species *Polyporella decora* Gorjunova. It is 40 to 50 m thick.

(7) Silty claystones and limy-clayey siltstones, both of a brownish-grey color. Among them, there are sporadic interbeds of clayey limestones with indeterminable organic detritus and reticulate tracks of limivorous organisms. The claystones include rounded concretions consisting of siliceous, clayey, and calcareous matter. It is 80 to 125 m thick.

(8) Brownish-grey limy-clayey sandstones (with a carbonate content of up to 40%) with rare tracks of vital activity (including those of the *Chondrites* type), and fossils represented by crinoids, the bryozoans *Ramoporida asiatica* Gorjunova, *Fenestella pamirensis* Gorjunova, and *Pamirella nitida* Gorjunova, and the brachiopods *Taeniothaerus rusticus* Grunt, *Reticulatia pamirica* Grunt, *Cancrinella altissima* King, "*Gerassimovia*"[2] *bactriana* Grunt, *Neospirifer joharensis*

[2] Grunt (Grunt and Dmitriev, 1973) erroneously included the *Gerassimovia* genus in the Tashkazyk assemblage. The peculiarly larger rhynchonelloids, referred earlier to this taxon, should be described as an original endemic genus.

Diener, *Kitakamithyris petaliformis* Pavlova, *Tiramnia uralica* (Tschernyschew), and *Cleiothyridina ailakensis* (Reed). It is 5 to 9.5 m thick.

(9) Black (yellowish-grey on the surface) claystone with interlayers of sandy-clayey siltstones. Near the top of the bed, the rocks are ferruginated, which is probably related to the weathering crust. Such features at the top of the Tashkazyk Formation are typical of most sections of both the Kastanat–Djilga and Karabeles types. It is more than 20 m thick.

Nearly everywhere, the eroded upper surface of the Bazardara Formation is overlain by a basal bed of limestones bearing abundant brachiopods and ammonoids of the Kyzyl–Djilga Horizon of the Bolorian stage (*Ob"yasnitel'naya* ..., 1989).

Another section of the Kastanat–Djilga type is located in the Kurteke River valley. Only the upper part of the Tashkazyk Formation is exposed here. In addition to the remnants of crinoids, bivalves, corals, and organic detritus, the clayey and sandy limestones, occurring at the top of the Tashkazyk Formation, contain the bryozoans *Ramoporida asiatica* Gorjunova, *Dyscritella vulgata* Gorjunova, and *Fenestella pamirensis* Gorjunova along with abundant brachiopods *Wardakia grandis* (Waagen),[3] *W. diversa* (Reed),[3] *Taeniothaerus rusticus* Grunt, *Reticulatia pamirica* Grunt, *Cancrinella altissima* King, *"Gerassimovia" bactriana* Grunt, *Punctocyrtella spinosa* Plodowski, *Neospirifer joharensis* (Diener), and *Cleiothyridina ailakensis* (Reed). Sections of the Tashkazyk Formation are correlated according to characteristic features recognized in the Kastanat–Djilga locality (Fig. 2), where the basal member with lumps and boulders (Bed 3) is overlain by rhythmically alternating sandstones and claystones (Bed 4, the flyschoid member), which in turn grade upwards into mostly clayey deposits (Bed 5, the supraflyschoid member). The mentioned beds compose the lower subformation of the Tashkazyk Formation, while the rest of the section comprising claystones and siltstones (beds 6 - 9) belongs to the upper subformation. Though the sections are definitely comparable, the facies composition of their lump-boulder member is clearly variable. For example, in sections of the Kastanat–Djilga type, it includes the dominant limestone fragments, whereas boulders of quartzite and greywacke sandstones common in other localities are absent here. In addition, the fragmented calcareous rocks of the Kastanat–Djilga sections seem to be mainly in the original occurrence, i.e., unaffected by a significant transportation.

The oldest fauna of the Bazardara series was collected from the upper part of the Uruzbulak Formation, from where a form such as *Glaphyrites* sp. was defined (Dmitriev, 1976; Leonova and Dmitriev, 1989). Accordingly, the Uruzbulak Formation can now be con-

[3] Among the *Debria* forms, Termier *et al.* (1974) recognized the separate genus *Wardakia*, and referred *D. grandis* Waagen to this taxon. A similar specimen *D. diversa* Reed probably also belongs to the same genus.

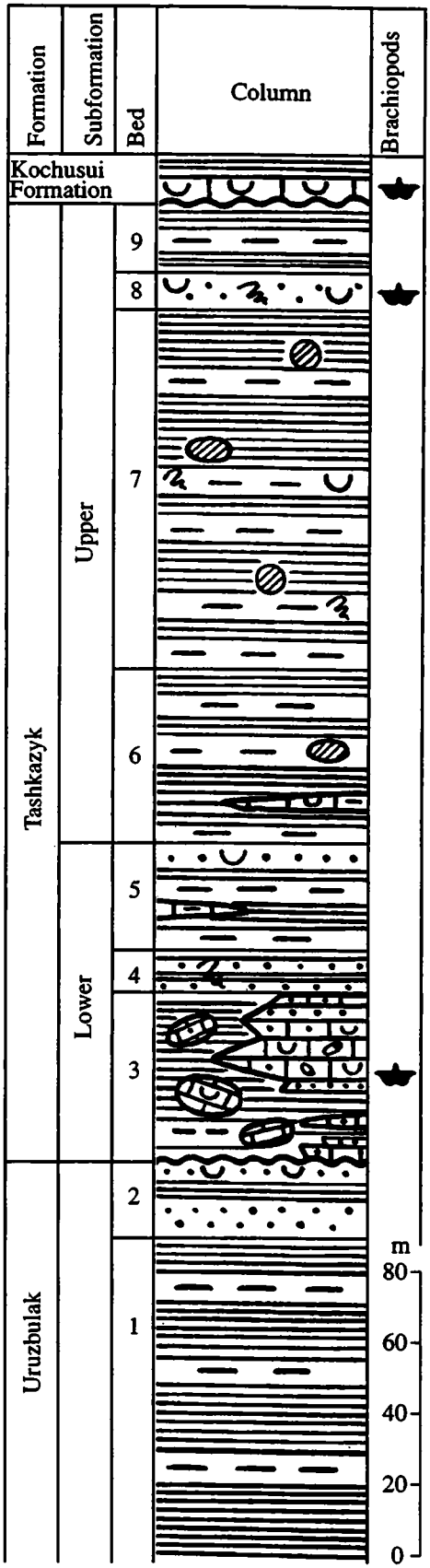

Fig. 2. Bazardara Group section in the Kastsnat–Djilga River valley (see text for description).

ventionally referred to the Carboniferous of an unclear stratigraphic range (*Ob"yasnitel'naya ...*, 1989).

FAUNAL CHARACTERISTICS AND AGE OF THE TASHKAZYK FORMATION

The faunal characteristics of the Tashkazyk Formation are quite extensive. Many investigators (B.M. Gushchin, T.A. Grunt, V.Yu. Dmitriev, E.Ya. Leven, V.M. Dronov, T.B. Leonova, and V.P. Novikov) have collected its fossils during the last 30 years. Additional paleontological materials were obtained as a result of the geological survey in the 1960's. The problem of the Tashkazyk Formation age has been comprehensively discussed (Gorjunova, 1975; Grunt and Dmitriev, 1973; Gushchin, 1966, 1969; Dmitriev, 1976; Leonova and Dmitriev, 1989; Novikov, 1976, 1977, 1979; Ruzhentsev, 1978). All the current opinions are controversial, although the suggested Visean–Namurian age (Gushchin, 1966) is unacceptable. The age of the Tashkazyk Formation can be reliably determined according to a representative ammonoid assemblage revealed by Grunt and Dmitriev (Dmitriev, 1976) from the Shor-Bulak-Sai locality. The assemblage was described in detail by Ruzhentsev (1978). This author concluded that according to its taxonomic composition and evolutionary stage, the studied ammonoids and their host rocks are of the Late Asselian. Judging from its correlation with an ammonoid assemblage from an outcrop located on the left slope of the Aksu Valley between the Sul'-Istyk and Kur-Istyk rivers, the stratigraphic position of the above assemblage corresponds to the top (near the upper boundary) level of the Tashkazyk Formation (Leonova and Dmitriev, 1989). A similar taxonomic composition was defined in the ammonoid assemblage from upper beds of the Maping Formation, Guangxi province, southern China. The coexisting fusulinids from the same beds belong to the genera *Pseudoendothyra, Schwagerina, Pseudoschwagerina, Rugosofusulina*, and *Triticites*. These taxa also suggest the Asselian stage of host deposits, but it is not inconceivable that they may be of Sakmarian age (Zhou Zu-ren, 1987).

Moreover, bryozoans described by Goryunova (1975) indicate the Artinskian age of the Tashkazyk Formation. The bivalve species *Oriocrassatella* aff. *stokesi* Etheridge from the top of the Uruzbulak Formation and *Megadesmus globosus* Sowerby from the lump-boulder member have stratigraphic ranges restricted by the Sakmarian and Artinskian stages, thus supporting this conclusion. Brachiopods usually occur in the Tashkazyk Formation sections of Kastanat–Djilga type at different stratigraphic levels. At the upper level, they were detected in three localities: Kastanat–Djilga, Kurteke, and Chakobai (Grunt and Dmitriev, 1973). In addition to the Kastanat–Djilga section, brachiopods at the basal level of the Tashkazyk Formation were recognized in several localities along the river valleys of South Ak-Arkhar, Zor-Akbura, Muzdu-Bulak, West Igrimyuiz Karabeles, Sul'-Istyk, and Kur-Istyk. The fossils were collected mainly from the lump-boulder member (Fig. 3), and include the following species: *Wardakia* sp., *Permochonetes pamiricus* Afanasjeva, *Cancrinella* ex gr. *farleyensis* (Etheridge et Dun), *"Gerassimovia"* ex gr. *bactriana* Grunt, *Neospirifer* ex gr. *joharensis* (Diener), *Punctocyrtella* sp. nov., *Notospirifer* sp. nov., *Kitakamithyris petaliformis* Pavlova, *Tiramnia uralica* (Tschernyschew), and *Cleiothyridina* sp. Fragmented brachiopod remnants occur almost throughout the entire section, but they are usually poorly preserved. The upper Tashkazyk assemblage consists of the following forms: *Wardakia grandis* (Waagen), *W. diversa* (Reed), *Permochonetes pamiricus* Afanasjeva, *Taeniothaerus rusticus* Grunt, *Reticulatia pamirica* Grunt, *Cancrinella altissima* King, *"Gerassimovia" bactriana* Grunt, *Neospirifer joharensis* (Diener), *Punctocyrtella spinosa* Plodowski, *Kitakamithyris petaliformis* Pavlova, *Tiramnia uralica* (Tschernyschew), and *Cleiothyridina ailakensis* (Reed). Although some poorly preserved brachiopods of the lower Tashkazyk assemblage were classified solely according to the open nomenclature, a comparative analysis of the two lists shows that they are very similar, especially at the generic level. The common genera in them are *Permochonetes, Cancrinella, "Gerassimovia," Neospirifer, Punctocyrtella, Kitakamithyris*, and *Cleiothyridina*. The lower Tashkazyk assemblage contains no *Taeniothaerus* and *Reticulatia* genera, while only the *Notospirifer* genus is missing in the latter. As for the specific composition, the common forms of both assemblages are *Permochonetes pamiricus* Afanasjeva, *"Gerassimovia" bactriana* Grunt, *Kitakamithyris petaliformis* Pavlova, and *Neospirifer joharensis* (Diener). Therefore, we are dealing in fact with a single assemblage corresponding evidently to a single stratigraphic level.

Analyzing the stratigraphic distribution of brachiopods of the upper Tashkazyk assemblage, Grunt (1973) concluded that their host deposits are Sakmarian–Early Artinskian in age. Their upper boundary is defined by the overlying Boz-Tere ammonoid assemblage, which was referred earlier to the Upper Artinskian (*Ob"yasnitel'naya ...*, 1980). Leonova and Dmitriev (1989) favored the Kungurian age of the assemblage, which is why the upper boundary of the Tashkazyk Formation can be placed higher, as high as the upper boundary of the Artinskian Stage. This agrees with data on brachiopods and bryozoans, but contradicts Dmitriev's (1976) opinion that the Shorbulak assemblage of ammonoids must be placed between the lower and upper brachiopod assemblages of the Tashkazyk Formation.

The available data shows that the Tashkazyk brachiopod assemblage includes in total 15 species of 12 genera. Its two genera (*Permochonetes* and *"Gerassimovia"*) and seven species are endemic taxa of the Early Permian basins of the southeastern Pamirs, and cannot serve as indicators of the stratigraphic position of the assemblage. Six genera (*Reticulatia, Cancrinella, Neospirifer, Kitakamithyris, Tiramnia*, and *Cleiothyridina*) are

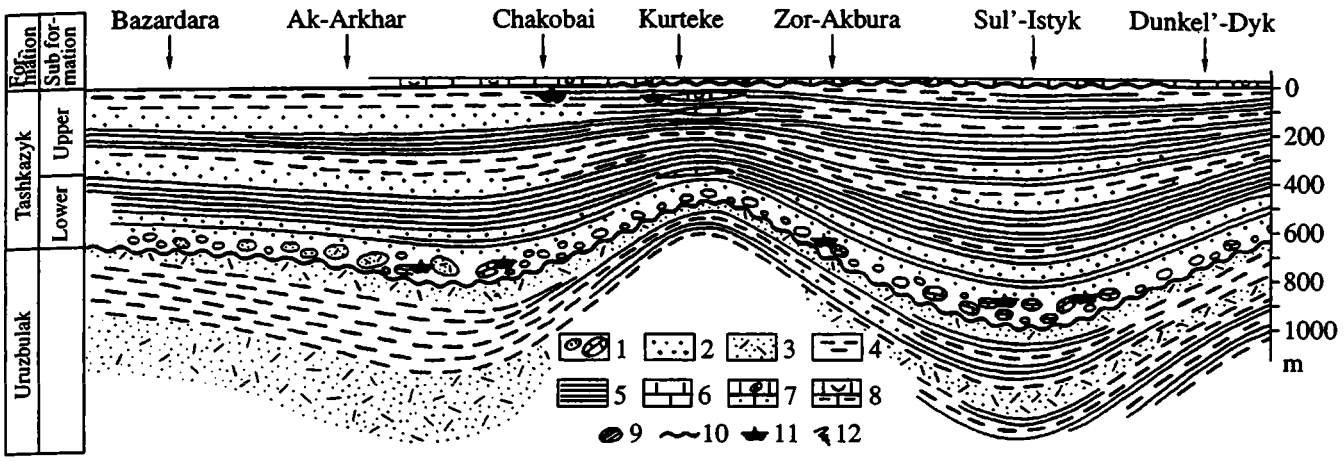

Fig. 3. Lithostratigraphic profile through the Bazardara Group deposits.

1 – lumps and boulders; 2 – sandstones; 3 – greywacke sandstones; 4 – siltstones; 5 – claystones; 6 – limestones; 7 – sandy limestones with pebbles of quartz and siliceous rocks; 8 – organoclastic and clayey limestones; 9 – concretions; 10 – unconformable boundaries; 11 – brachiopod assemblages; 12 – traces of vital activity (see Fig. 2 for details).

widely distributed geographically, and have a considerable stratigraphic range. Of the remaining five, the *Taeniothaerus* genus occurs in deposits of the *Taenothaerus–Buxtonia–Polypora* Zone in Kashmir (Nagmarg beds, Agglomerate Group), in the Amb Formation (lower *Productus* limestones) of the Salt Range, in the Upper Sakmarian deposits of the Wardak province of central Afghanistan, in the Lusaba Formation of eastern Arabia, and in the Lower Permian deposits of Australia and Tasmania, namely in the upper part (Hardman Member) of the Liveringa Formation and in the Carnarvon Beds of Wandagee and Fossil Cliff formations in West Australia, as well as in the Jarrol Beds of the Cattle Creek Formation and Homevale Beds in Queensland. An endemic species of the *Taeniothaerus* genus was recently described by Archbold (1991) as occurring in the Upper Sakmarian (Sterlitamak Substage)–Lower Artinskian (Aktasta Substage) deposits of the Irian–Java province (western New Guinea). The deposits correlate well with the Aiduna Formation and the Aifam and Agglomerate groups of Kashmir, which occupy the same stratigraphic interval. Unverified *Taeniothaerus* forms have been reported to occur in member "D" of the Geirud Formation of northern Iran.

The *Punctocyrtella* genus is described among fossils from the Lusaba Formation of southeastern Arabia, the Nagmag Beds of Kashmir, and the Sakmarian deposits of central Afghanistan. Plodowski, the author of the genus, also suggested its presence in the Lower Permian strata of Australia.

The *Notospirifer* genus is widespread in the Permian deposits of Queensland (East Australia), from their Homevale Beds to the *Streptorhynchus* Zone (i.e., from the Sakmarian to the assumed Kazanian deposits). In the New Zealand, this genus was encountered in the Letham Formation and Productus Creek Group, which both correlate with the Kungurian–Ufimian deposits. In addition, the *Notospirifer* genus was tentatively recognized in the *Eurydesma–Conularia* beds of the Nilavan Group of the Salt Range. Similar forms were described by Termier *et. al.* (1974) as the *Tomiopsis* assemblage from the Sakmarian deposits of Wardak province. The *Wardakia* genus is known to occur in the Upper Sakmarian deposits of central Afghanistan, and also in the Amb Formation of the Salt Range and Basleo Formation of Timor.

The taxonomic analysis of the Tashkazyk assemblage shows that only 8 of the available 15 species do not belong to endemic forms, and that some of them are widespread. For example, *C. altissima* is a form of the Upper Carboniferous and Lower Permian strata of Texas, while *T. uralica* occurs in the Asselian deposits of the Urals. Four other species are evidently related to the Permian basins of the peri-Gondwanian margins: *W. grandis* is known as a common form in the Upper Sakmarian deposits of central Afghanistan, the Amb Formation of the Salt Range, and the Basleo Formation of Timor; *W. diversa* originated from the Upper Permian strata (Amb and Vargal formations) of the Salt Range; *N. joharensis*, from the *Productus* shales of Kumaon referred to the Djulfian and even Dorashamian stages of the Upper Permian; and *Cl. ailakensis*, from the Lower Permian horizons of Chitral adjacent to the southeastern Pamirs. Species such as *P. spinosa* and *C.* ex gr. *farleyensis* are particularly significant in the study of paleogeographic and biogeographic environments. The first one occurs in the Nagmarg Beds of Kashmir, and was described as a form of *Licharewia spinosa* in the Upper Sakmarian deposits of the Wardak locality. The second species is widespread in the Takitimi Group rocks of New Zealand, corresponding to the Sakmarian–Artinskian deposits, and in the lower part of the Productus Creek Group, which is still referred to the Kungurian–Ufimian interval. A similar species, *C. magniplicata* (Campbell), is also characteristic of the New Zealand basins.

Therefore, analyzing the geographic and stratigraphic distribution of fossils composing the Tashkazyk assemblage, we can conclude that it clearly shares common features with the Early Permian assemblages of the Australia–New Zealand region, central Afghanistan, Kashmir, Pakistan, Arabia, and to a lesser extent with those of Iran. The correlation of the Tashkazyk Formation and comparable sections are supported by the following. In Australia and New Zealand, the earliest horizon with *Taeniothaerus, Notospirifer,* and larger *Cancrinella* (of the *C. farleyensis* and *C. gigantea* type) belong to the Sakmarian Stage, as implied by the coexisting Early Sakmarian (Tastubian) ammonoid *Juresanites jacksoni* (Etheridge) in the Holmwood shales and by *Metalegoceras clarkii* (Miller) in the overlying Nura Nura Beds of the West Australian Kalitara Formation. These forms are similar to *M. australe* (Smith) from the Bitauni Formation of Timor and to *M. hudsony* (Miller et Furnish) from the Haushi Formation of Arabia. Both species indicate the Late Sakmarian (Sterlitamak Stage) age of the enclosing rocks (Glenister *et al.*, 1973). In Australia and New Zealand, evolved brachiopod assemblages with *Taeniothaerus, Notospirifer,* and related diverse *Ingelarella* genus associated with larger *Cancrinella* forms are characteristic of the younger Artinskian deposits and can be encountered higher, as high as the Upper Permian strata.

In Kashmir (Dickins, 1985), a brachiopod assemblage resembling that of the Tashkazyk locality was noted in the *Taeniothaerus–Buxtonia–Polypora* Zone of the Nagmarg Beds,which is a member of the Agglomerate Group. It includes *Wardakia* sp., *Buxtonia kashmiricus* (Reed), *B. scabriculus* (Davidson), *Taeniothaerus permixtus* (Reed), *T. brenensis* (Reed), and *Fusispirifer plicatus* Waterhouse. According to Nakamura and Kapoor (1977), the Nagmarg Beds correspond to the upper part of the regiostage B(B_2) in West Australia, which is similar to the Sterlitamak Substage.

In southeastern Arabia, corresponding brachiopod assemblages are confined to the Lusaba Formation, which is apparently at the level of the *Metalegoceras* Beds of the Haushi Formation (Hudson and Sudbury, 1959). In Indostan, the oldest and most typical marine deposits of the postglacial period contain poor brachiopod assemblages, and are referred to as the Umaria Beds. They correlate with the Lyons facies of the Asselian Stage (regiostage A) in West Australia and with the lower part of the Kalitara Formation of the Tastubian age (substage B_1). The overlying Badhaura (Rangit) Beds comprise two faunal levels. The lower one, which has abundant *Oriocrassatella* gastropods and bivalves, correlates with the B_1 substage in West Australia. The upper level is marked by abundant brachiopods similar in taxonomic composition to the Tashkazyk assemblage. It corresponds to substage B_2, or even to stage C of West Australian scale (Dickins and Shah, 1977), i.e., to the Artinskian Stage, when European units are considered. In the Wardak locality of central Afghanistan, Termier *et al.* (1974) described a thick (up to 400 m) sequence of shales and sandstones with abundant fossils. The Upper Sakmarian part of the section bears such brachiopod genera as *Wardakia* and *Taeniothaerus* along with many species similar to those of the Tashkazyk assemblage. In the Salt Range sections, the *Notospirifer* genus was noted in the *Eurydesma–Conularia* Beds of the Nilavan Group referred conventionally to the Sakmarian. Here, as in the southeastern Pamirs, representatives of the *Notospirifer* genus associate with conulariids and bivalves resembling *Eurydesma* (*Oriocrassatella*) forms. The Nilavan Group occurs at the base of the well known Zalukh Group deposits ("Productus limestones"). Its deposits were interpreted to be tillite facies grading into marine sandstones (Kummel and Teichert, 1970). Therefore, the above correlation of sections similar in brachiopod assemblages and data on ammonoids suggest that during the Early Permian the southeastern Pamirs was a peri-Gondwanian province. The Tashkazyk brachiopod assemblage should be considered to belong to the Early Permian, but not older than the Sakmarian and not younger than the Artinskian.

PERI-GONDWANIAN PALEO- AND BIOGEOGRAPHY DURING THE EARLY PERMIAN

Peculiarities of fossil assemblages of the southern Pamirs and lithostratigraphic characteristics of host deposits allow us to interpret them paleo- and biogeographically only from the standpoint of mobilism. Accordingly, the Permian Paleotethys must be considered as a large sea basin (Fig. 4) situated between the Laurasian continental group in the north and Gondwana supercontinent in the south. To the west, the basin was receding in the Tunisia–Apennines region, thus resulting in both its paleo- and biogeographic isolation from the low-latitudinal North American basin. Indirect connections between them were possible only through the vast paleo-Pacific ocean located to the east. According to a recent reconstruction by Scotese and McKerrow (1990), the eastern part of the Paleotethys comprised three microcontinents: the North China (North China-Korean and Tarim plates), South China (Yangtze platform), and Indochina blocks. In submeridional succession, they all occupied subtropical regions, and only the northern areas of the North China block (Tarim plate) extended into temperate latitudes of the northern hemisphere. Scotese and McKerrow define these three blocks as the Kathasian group of microcontinents. Arabia, Indostan, and central South Afghanistan represent blocks of the Gondwanian margin, along which the microcontinents of Turkey, Iran, and Tibet were situated. The Australian platform and adjacent Sina–Burma massif, which presumably detached from it in the Late Devonian, occupied the most easterly position. At the end of Late Carboniferous and probably at the very beginning of the Permian, many regions of Africa, East Arabia, Indostan, the Sina–Burma massif, and the Australian platform experienced very intensive glaciation, as is evident from

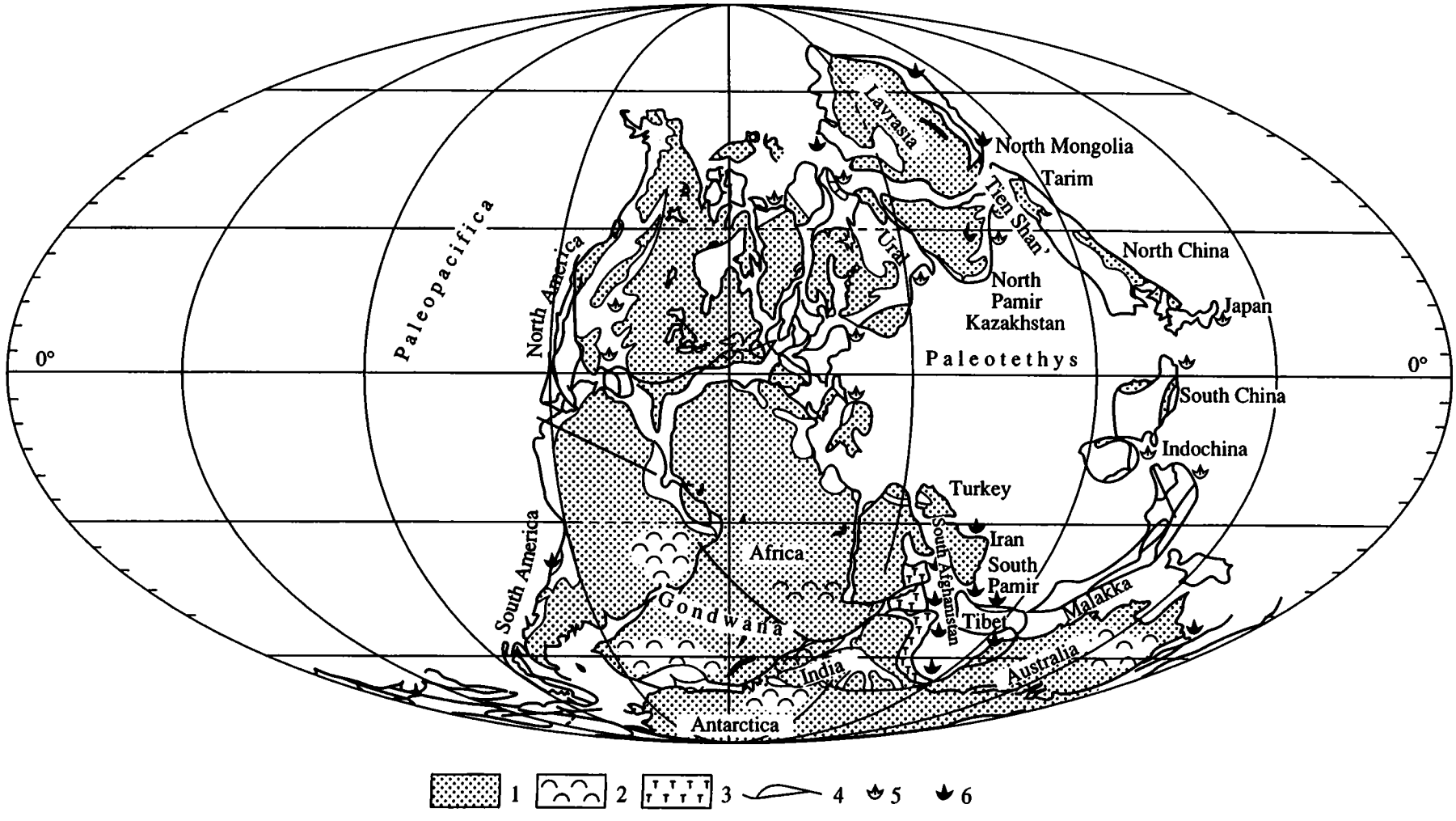

Fig. 4. Palinspastic scheme for the Carboniferous–Permian boundary period after Scotese and McKerrow (1990).

1 – land; 2 – main regions of glaciation; 3 – distribution areas of greywacke deposits ("agglomerate shales"); 4 – generalized boundaries of microcontinents and intracontinental sea basins; 5 – tropical to subtropical brachiopod assemblages; 6 – nontropical (Notal and Boreal) brachiopod assemblages.

lithologic data and peculiarities of fossil assemblages (Dickins, 1983). The glaciation left behind thick moraine deposits in South Africa, Antarctica, South America, Arabia, India, Tibet, and Australia. These widespread deposits are, according to pollen and flora remnants, Late Carboniferous–Asselian in age. The intensive thawing of ice sheets and the following rise in sea level were probably very quick, as indicated by traces of a rapid transgression that affected all the peri-Gondwanian provinces during the Early Sakmarian (Tastubian) time. In most regions under consideration, fossils of marine invertebrates first occur in beds right above the glacial deposits. For example, in West Australia, postglacial deposits contain marine fauna of the Tastubian level, as noted above. It is worth noting that the Early Permian brachiopod assemblages from postglacial deposit are peculiar. So, the characteristic Gondwanian taxa (*Taeniothaerus, Notospirifer, Ingelarella, Punctocyrtella*, and others) never occur in sections of northern shelf provinces of the Tethys, which is typical of other faunal groups as well. For example, sections of the Bazardara Group entirely lack fusulinids. Their assemblages are very poor and monotonous in sections of the central Pamirs, Himalayas, Karakorum, Pakistan, and southern Afghanistan. Simultaneously, they contain widespread bivalve forms: *Eurydesma* and *Conularia*. In the lump-boulder member of the Tashkazyk Formation, there are many other bivalve mollusks, such as representatives of the genera *Cleiobis, Pseudomyalina, Chaenomya, Cypriceidina, Edmondia*, and *Streblopteria*, which, in Kushnar's opinion, were typical of biota of the Early Permian basins in Australia. This peculiar type of fauna corresponds to lithologic features of the Tashkazyk Formation. Like the entire Bazardara Group, it is very similar to coeval clayey-terrigeneous formations of the peri-Gondwanian shelf zone of the Paleotethys, namely to the Siahkokh Group of Afghanistan, Nilavan Group of Pakistan, Barakar Formation of India, Khornatso Formation of Karakorum, and the Agglomerate Group of Kashmir, Nepal, and other regions of the Himalayas (Gansser, 1967). These sections have the following common features: a significant thickness (100 m or more), flyschoid intercalation of sediments, and a higher proportion of calcareous rocks grading into pure carbonate deposits in the upper part. Generally monotonous in structure, they regularly include polymict boulder-conglomerate horizons (of a tillite type), as well as interbeds and lenses of sandy limestones with Gondwanian fauna. Their fine-grained rocks are surprisingly similar in composition and comprise very remarkable greywacke ("agglomerate") sediments, the matrix of which consists of volcanic, granitoid, quartzite, limestone, and angular quartz clasts. These features suggest common provenances for the peri-Gondwanian sedimentary basins and similar depositional environments. In northern and southern coastal zones of the Paleotethys, the volcanic activity and sedimentogenesis were very different. The shallow carbonate facies with reef buildups and bioherms are characteristic of the Lower Permian sections of the Darvaz type, differing from sections of the southern Pamirs, where sedimentation was dominantly clastic and occurred in settings with a considerable depth range, which favored submarine sliding processes. The volcanic rocks, fairly abundant among the Lower Permian beds of the Darvaz–Transalai zone, but very rare in the Bazardara Group, in the first case are represented by a calc–alkaline andesite series, and by subalkaline basaltoids in the second.

According to modern reconstructions, the northern coast of the Paleotethys was entirely confined to the equatorial zone. This resulted in the accumulation of widespread monofacial sediments bearing similar assemblages of fossils, which characterize the Asselian–Sakmarian deposits of the Urals, Fergana, northern Afghanistan, southwestern Darvaz, and southern China. The different paleogeographic position was probably responsible for the different character of fauna in the northern and southern shelf provinces of the Paleotethys. That difference was most distinct at the beginning of the Permian (Leven and Shcherbovich, 1978), when littoral benthic assemblages of the southern coast of the Paleotethys were affected by glaciation in Gondwana. Later, when the climate became more moderate and warm enough to thaw ice sheets, the differences between the northern and southern Tethys assemblages became less evident. In addition, the southern coast of the Paleotethys occupied various positions relative to equator. It was located close to 60°S at the beginning of the Permian, and close to 40°S at the end of that period. The northern coast was then close to 25°N, as indicated by paleomagnetic data for the Lower Permian rocks of the Darvaz sections. The mean water temperature was 22.5 ± 2°C (Davydov *et al.*, 1983).

At present, provinces of opposite coasts of the Paleotethys are in contact along the main Hindu Kush fault. The Tanymas (Vanch–Akbaital) fault in Pamirs and central Badahshan fault in Afghanistan are separate segments of this suture zone (Termier and Termier, 1977; Leven and Shcherbovich, 1978; Belov, 1981; and others).

To summarize, we may now confidently conclude that, during the Early Permian, the southeastern Pamirs was a peri-Gondwanian province. The Lower Permian (Pre-Kungurian) Tashkazyk assemblage of brachiopods is a Gondwanian type and does not include northern Tethyan elements. The Asselian brachiopod assemblages have not been detected within the southern Tethyan provinces. Their oldest postglacial assemblages are most probably Sakmarian in age. Many brachiopod forms are widespread throughout the overlying (Artinskian) deposits of Australia, Tasmania, and New Zealand. A direct correlation between the studied assemblages and those from the Ural stratotypes is impossible, because they were dependent on different climatic, paleo-, and biogeographic factors.

Reviewers E.Ya. Leven and A.G. Ponomarenko

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Early and Middle Jurasic Ostracods of Northern Siberia: Principal Regularities in Evolution and the Zonal Scale

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Abstract – The detailed investigations of numerous Lower and Middle Jurassic sections in the northern area of the Asian part of Russia and microfossils encountered in them allowed us to determine that sequences of the ostracod assemblages persist over long distances. On this basis, the ostracod zones ("o-zones") and beds are distinguished and traced in the studied sequences of the Yenisey–Lena depression, Verkhoyansk region, the Vilyui syneclise, northeastern Russia, and northern West Siberia. The zonation schemes of some regions, correlated according to ostracods, as well as the paleontological characteristics of the distinguished units are presented. The age determinations of o-zones based on correlation with the ammonite scale ("a-zones"), or with the bivalve ("b-zones") and foraminiferal ("f-zones") zonations are discussed. The dynamics of the ostracod taxonomic diversity in the Lower and Middle Jurassic sequences, and the microcyclicity of their distribution within separate stratigraphic levels are also considered. The feasibility of circumboreal and interregional correlations of the Toarcian deposits according to ostracods is discussed. The description of the new subgenus *Camptocythere* (*Anabarocythere*) subgen. nov. and its characteristic species is presented.

INTRODUCTION

Marine ostracods were widely distributed in the Early and Middle Jurassic paleobasins. The stratigraphy of this fauna group is of great importance for the oil industry, as ostracod remains are often found in abundance in cores of boreholes. Both the taxonomy (Grundel, 1964; Lord, 1971; and others) and biostratigraphy (Michelsen, 1975; Riegraf, 1985; and others) of the Jurassic marine ostracods are under active study. Ostracod zonation scales were elaborated recently for the Early Jurassic of England (Bate, and Coleman, 1975; and others), Germany (Riegraf, 1985; Knitter, 1984; and others), Denmark (Michelsen, 1985), Sweden (Sivhed, 1980), and other regions. In most cases, the units distinguished by ostracods are either zones of mutual distribution, complex zones, or, in places, rank zones.

Sharapova (1940) and Gerke (1953) were the first to report initial data on the Lower-Middle Jurassic ostracods of northern Siberia. Later, Lev (1958, 1961, 1966) presented micropaleontological characteristics and description of some typical species from the Jurassic sequences of the Yenisey–Khatanga depression and the lower course of the Lena River. As a result, several ostracod assemblages characterizing the ammonite zones and stages of the standard stratigraphic scale were adopted in the stratigraphic schemes for northern Siberia (*Resheniya ...*, 1981; *Stratigrafiya ...*, 1976). At the same time, some species typical of the assemblages were insufficiently described. Insufficient knowledge about the ostracods impedes further development of biostratigraphic schemes for the Lower and Middle Jurassic of northern Siberia.

MATERIAL AND THE INVESTIGATION METHOD

The study of ostracods collected from the Jurassic deposits of the eastern Taimyr, Yuryung-Tumus Peninsula, Anabar region, Olenek River basin, Verkhoyansk region, Vilyui syneclise, Levyi Kadon River basin (northeastern Russia), northern West Siberia (Fig. 1), as well as the analysis of published data on their distribution in the Vilyui syneclise, Verkhoyansk and other regions of the northern Siberia (*Stratigrafiya ...*, 1976; Lev, 1958; 1966; and others) showed that the taxonomic diversity of ostracods is much greater than was earlier believed. Accordingly, the paleontological characteristics of the Jurassic biostratigraphic units distinguished by ostracods in northern Siberia and northeastern Russia were considered in greater detail.

Ostracods occur more rarely than foraminifers in the Lower-Middle Jurassic deposits of Siberia. Nevertheless, species successions for the *Ogmoconcha* genus during the Lower and Middle Lias, and for the *Camptocythere* genus during the Upper Lias and Middle Jurassic are persistent throughout the territory, are of an euryfacial character, and show high rates of evolution. This applies to, in particular, representatives of the *Camptocythere* genus.

The distribution of ostracods in the Lower-Middle Jurassic deposits of Siberia is irregular with regard to both taxonomy and abundance (Fig. 2). Thus, in the Lower Hettangian sequences (the downstream area of

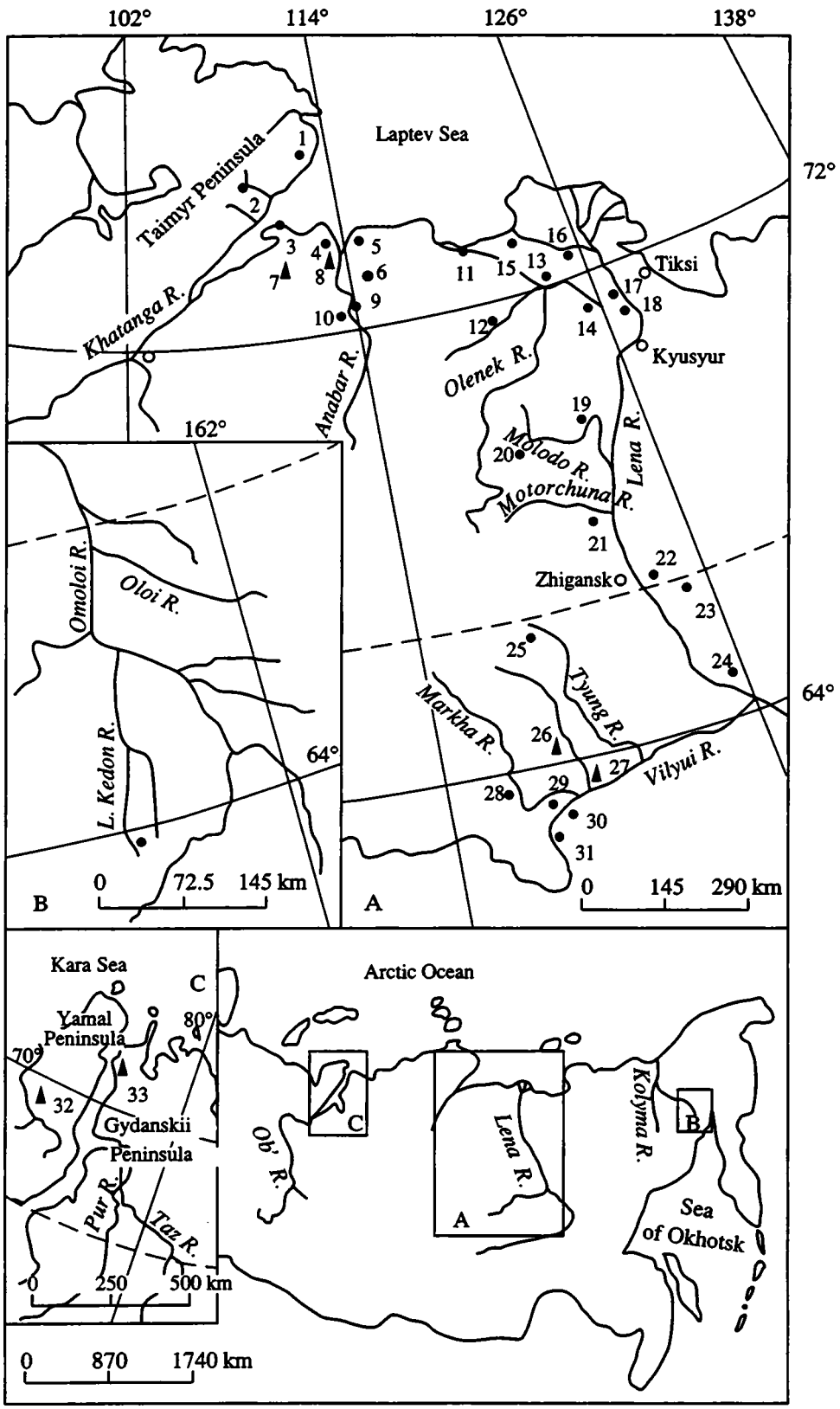


Fig. 1. Location of principal Lower and Middle Jurassic sections in the North Asian part of Russia.

1, 2 – Eastern Taimyr; 3 – Nordvik region; 4 - 10 – Anabar region; 11 - 16 – Kelimyar–Olenek region; 17 - 18 – lower stream of the Lena River; 19 - 21 – western Verkhoyansk region; 22 - 24 – eastern Verkhoyansk region; 25 - 31 – Vilyui syneclise; 32 - 33 – northern part of West Siberia. Dots – natural exposures; triangles – drilling sites.

the Olenek River basin), rare representatives of the genera *Ogmoconcha*, *Ogmoconchella*, and *Paracypris* are recorded. In the overlying deposits (Upper Hettangian–Lower Pliensbachian), the taxonomic diversity decreases, and only individual species of *Ogmoconcha longula* are found. In the Upper Pliensbachian (the *Amaltheus stokes*–lower *Amaltheus viligaensis* a-zones), the representatives of the genera *Ogmoconcha*, *Nanacythere* and "*Mandelstamia*" are once again abundant, whereas those of the *Ogmoconchella* genus are rare. In the Uppermost Pliensbachian and Lowermost Toarcian deposits (the upper *Amatheus viligaensis–Tiltoniceras propinquum* a-zones), ostracod diversity and abundance again decrease: only individual specimens of *Ogmoconcha* and *Ogmoconchella* have been revealed here. An abrupt change in the assemblages occurred near the boundary between the *Tiltoniceras propinquum* and *Harpoceras falcifer* a-zones of the Lower Toarcian, where representatives of the Early-Middle Lias genera *Ogmoconcha*, *Ogmoconchella*, and *Nanacythere* completely disappear and do not occur in the overlying deposits. They were replaced by species of the genera *Trachycythere*, *Kinkelinella*, *Polycope*, "*Monoceratina*", and by abundant representatives of the *Camptocythere* (*Camptocythere*) genus. A similar reorganization and taxonomic reneval of the ostracod assemblages occurs approximately at the same level (from the uppermost *Dactylioceras tenuicostatum* to the lowermost *Harpoceras falcifer* a-zones) in many sections of Western Europe and Canada (Riegraf, 1985; Bate and Coleman, 1975; and others). This seems to be related to the Late Pliensbachian–Early Toarcian biota crisis experienced by different fauna groups thoughout the Boreal provinces (Hallam, 1978; Nikitenko and Shurygin, 1992; and others). The ostracod assemblages occuring in the Lower Toarcian–Lowermost Aalenian overlying deposits become distinctly poorer: only *Camptocythere* (*Camptocythere*) forms are found in them. In the Lower Aalenian deposits (the *Pseudolioceras maclintocki* a-zone), the ostracod diversity again increases slightly, though the assemblages are still impoverished. Single representatives of the genera *Camptocythere* (*Camptocythere*), *C.* (*Anabarocythere*), *Procytherura*, *Paracypris*, and *Orthonotacythere* are encountered at this level. In the Upper Aalenian and Lowermost Bajocian deposits (the *Tugurites whiteavesi* and *Tugurites fastigatus* a-zones), the ostracod assemblages gradually become poorer, reaching a diversity minimum in the Lowermost Bajocian. In the upper part of Lower Bajocian deposits (the *Normanites* Zone), the abundance and diversity of ostracods sharply increase. There are abundant species of the genus *Camptocythere* (Camptocythere), accompanied by numerous *Orthonotacythere* forms and frequent specimens of "*Monocaratina*," *Pyrocytheroidea*, and other taxa. Ostracods are rare in the Upper Bajocian and Lower Bathonian deposits, but, as before, still diverse.

The study of general regularities in the ostracod distribution through numerous Jurassic sections revealed a number of datum levels traced over the vast North

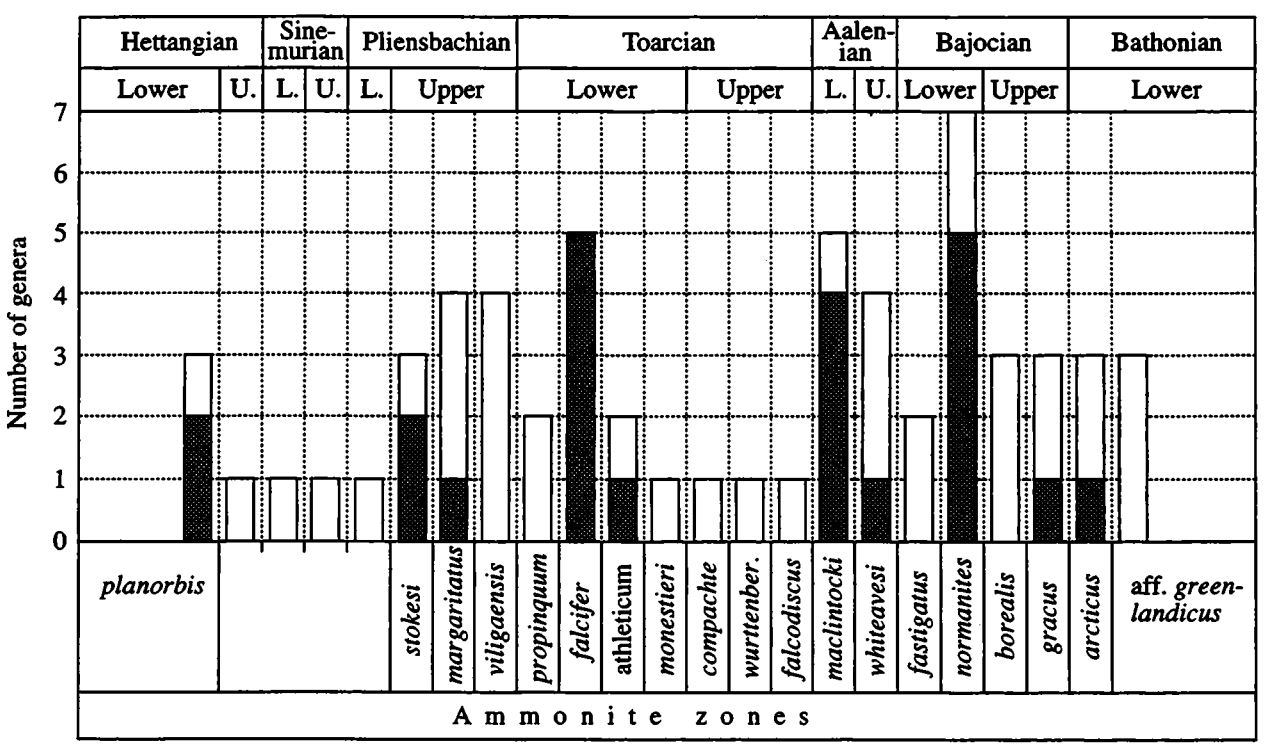


Fig. 2. Dynamics of ostracod diversity during the Lower and Middle Jurassic in the North Asian part of Russia. Shaded bars indicate the number of appearing genera.

Asian part of Russia, for instance, the *Camptocythere* o-zone of the Lower Toarcian and the *Camptocythere spinulosa* o-zone of the Lower Bajocian.

Against the background of the alternating epochs of high diversity and impoverishment of ostracods, among benthic biota of the Boreal basins, intriguing regularities are also noted for their facial affinity. So, when studying microcycles of the Lower Toarcian black, in places bituminous, clays I discovered that monospecific accumulations of ostracods with a thin carapace and well developed pore canals (*Capmptocythere* (*Camptocythere*) *mandelstami*) occur at boundaries of thin interlayers of black clays enriched in organic matter, whereas numerous and diverse foraminifers accumulate in lighter colored grey clays alternating with them (Nikitenko and Shurygin, 1992) (Fig. 3). Eurybiontic *Ammodiscus* and *Saccamina* forms rarely occur in the darkest colored clay laminae. This peculiar distribution of microbenthos and the Lower Toarcian sedimentary structure, observed in numerous sections everywhere, seems to be related to alternating periods of a stagnant and well aerated bottom water, as well as to a recurrent increase in the organic material supply into the sedimentation basin. The formation of the Lower Toarcian clays is usually attributed to a rise in the eustatic sea level (Hallam, 1978; and others). This was responsible for the ingression of representatives of the genera *Trachycythere, Polycope, Kinkelinella*, and "*Monoceratina*," which were widespread in the Toarcian seas of Western Europe, continuing into the Siberian paleobasin. In northern Russia, the Lower Toarcian clays are known in many sections of central and western Siberia, the Vilyui syneclise, the Verkhoyansk region, and the Barents Sea shelf. They seem to be similar to those in the North Sea, Western Europe, Arctic Canada, and Alaska.

In the upper part of Lower Bajocian deposits (the *Camptocythere spinulosa* o-zone), like in the Lower Toarcian, there are alternating laminae rich in either diverse ostracods or abundant foraminifers. Judging from the lithology, geochemical data (Levchuk, 1955), and the character and type of the benthos, this sequence was formed under normal marine conditions. It seems that laminae dominated by abundant *Camptocythere* (*Camptocythere*), *C.* (*Anabarocythere*), numerous *Orthonotacythere, Paracypris*, "*Monoceratina*" and other genera were formed under an oxygen deficiency that is in accordance with well-developed pores in their carapace walls and with the presence of bivalve shells of *Malettia, Nuculana*, and other anoxibionts flourishing in the oxygen-deficient environments (Zakharov and Shurygin, 1978). These laminae alternate with those formed in the periods when the bottom waters were well aerated and enriched in diverse and abundant foraminifers accompanied by less numerous ostracods.

The datum levels, traced in many sections and reliably dated by ammonites and bivalves, allowed us to precisely correlate sequences of ostracod assemblages and species in separate sections and, consequently, to distinguish the autonomous ostracod units. The boundaries between the units were defined by the appearance of new assemblages, and as the lower limits of epiboles of some species. The studied Lower-Middle Jurassic sections of northern Mid-Siberia and northeastern Russia showed that successions of the ostracod assemblages are persistent throughout the entire territory and can be used to subdivide and correlate Jurassic deposits. Many authors (Stepanov and Mesezhnikov, 1979; Shurygin, 1986; 1987a, b; 1989; and others) discussed principles that can be used to elaborate polytaxonic zonation scales based on benthonic fauna groups. Substantiatiing the age for ostracod zonation distinguished in northern Siberia relies upon the findings of associ-

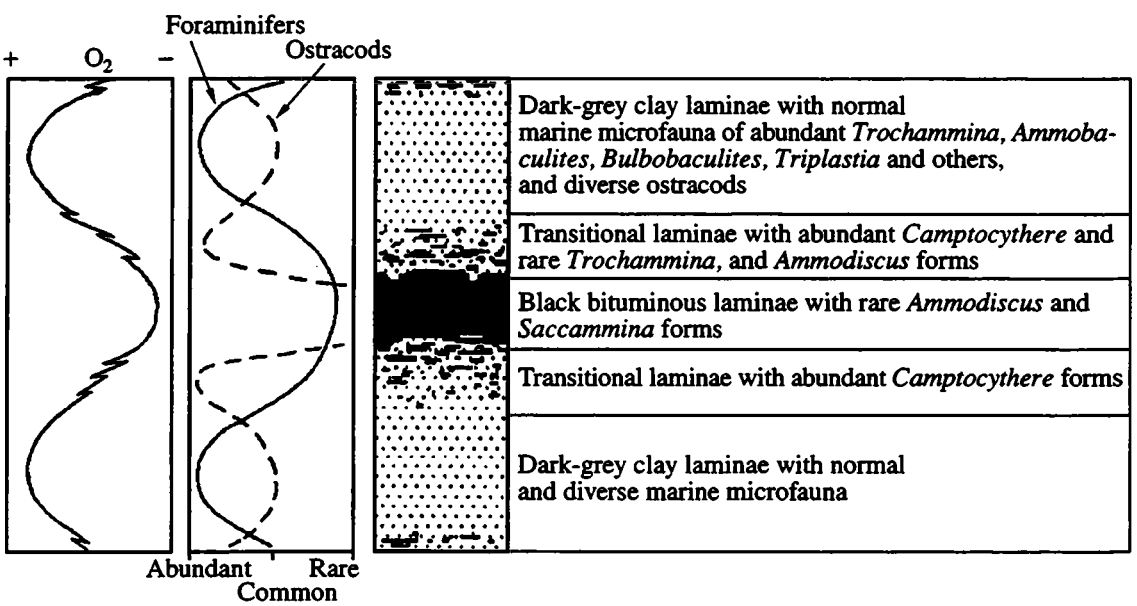

Foraminifers
Ostracods
+
O_2
–
Abundant
Rare
Common
Dark-grey clay laminae with normal marine microfauna of abundant *Trochammina, Ammobaculites, Bulbobaculites, Triplastia* and others, and diverse ostracods
Transitional laminae with abundant *Camptocythere* and rare *Trochammina*, and *Ammodiscus* forms
Black bituminous laminae with rare *Ammodiscus* and *Saccammina* forms
Transitional laminae with abundant *Camptocythere* forms
Dark-grey clay laminae with normal and diverse marine microfauna

Fig. 3. Distribution of microbenthos versus microlamination in the lower Toarcian black clays.

ated ammonites, or upon their distribution in sections of northeastern Russia, where the time ranges of ostracod assemblages are correlated to the ammonite scale. Age determination based on bivalve mollusks and foraminifers is also possible through the comparison of the successions of the bivalve and foraminiferal zones with those in the regions where such zones are characterized by ammonites. This was the basis for suggesting ostracod zonation for the Lower and Middle Jurassic deposits of northern Siberia (Table 1) (Nikitenko, 1990).

The stratigraphic section descriptions, their detailed lithological and paleontological characteristics, and numbers numbers are given according to the following publications: for the eastern Taimyr (Shurygin and Levchuk, 1982; Levchuk, 1985), Yuryung-Tumus Peninsula (Meledina *et al.*, 1987), the Anabar region (*Stratigrafiya* ..., 1976; Levchuk, 1985), northeastern Russia (Knyazev, 1991), and the Olenek River basin (Knyazev *et al.*, 1991). The stratotypes of the ostracod zones and their description are presented for the first time in this work.

SUBDIVISION OF LOWER AND MIDDLE JURASSIC DEPOSITS ACCORDING TO OSTRACODS

Ogmoconcha buurensis Beds

The index species: Ogmoconcha buurensis Nikitenko, sp. nov.

Representative ostracods (beside the index species): *Ogmoconchella* sp., and *Paracypris* sp. 1.

Boundaries: the lower boundary corresponds to the appearance level of the ostracod assemblage, and the upper one is marked by the appearance of *Ogmoconcha longula*, at which time the assemblage became impoverished.

The stratotype is located in the Olenek River basin (Buur River: Exposure 4; Exposure 2, 3, Members 1, 2; lower parts of Member 3) and is represented by dark-grey clays and silty clays 45 m thick (Knyazev *et al.*, 1991).

Occurrence: Northern mid-Siberia

Age: The Early Hettangian ammonites of the genera *Psiloceras* (Knyazev *et al.*, 1991), along with bivalve assemblage bearing *Meleagrinella subolifex* known in northeastern Russia, and Hettangian–Sinemurian ammonites (*Stratigrafiya* ..., 1976), are found in the section type of the *Ogmoconcha buurensis* Beds. In the foraminifer scale (Nikitenko, 1992), the beds correspond to the lower part of the *Trochammina* aff. *sablei* Zone.

Ogmoconcha longula Zone

The index species: Ogmoconcha longula Gerke et Lev, 1958.

Representative ostracods: *Ogmoconcha nordvikensis, Ogmoconchella ornata, O. olenekensis, O. conversa, Nanacythere costata,* "*Mandelstamia*" *lubrica,* and "*M.*" *linearis.*

Boundaries: the lower boundary is indicated by the appearance of *Ogmoconcha longula*, the upper one by a complete renewal of the ostracod assemblage and by an occurrence of *Camptocythere* (*C.*) *mandelstami.*

The stratotype is located on the western coast of the Anabar Inlet (Exposure 12, members 8 - 13) and represented by siltstone and grey or dark-grey clays, 136.5 m thick (Levchuk, 1985).

The parastratotype is situated in the Olenek River basin (Buur R., Exp. 2, 3 and Exp. 1, the upper part of Member 3 and Member 4) and represented by silty clays (about 50 m thick) with scattered pebbles and pyrite nodules, (Knyazev *et al.*, 1991).

Occurrence: North Siberia, northeastern Russia, and the northwestern Siberia

Age: the lower part of the *Ogmoconcha longula* Zone contains a bivalve assemblage of the upper *Meleagrinella subolifex* and *Harpax* ex. gr. *spinosus* beds, found in sections of northeastern Russia together with Hettangian, Sinemurian, and Early Pliensbachian ammonites. The upper part of the zone is reliably dated by ammonites in northern Siberia and northeastern Russia. For instance, specimens of *Amaltheus* cf. *stokes* occur in the Anabar Inlet area (*Startigrafiya* ..., 1976). Forms of *Amaltheus* sp. ind. are known in the middle part of the *Ogmoconcha longula* Zone of the same region, and those of *Amaltheus margaritatus* are found in the Yuryung–Tumus Peninsula section, (Meledina *et al.*, 1987). The uppermost part of the ostracod zone is barren of ammonites in northern mid-Siberia, but the bivalve assemblage of the upper part of the *Anradulonectites incertus* Zone is encountered here, which corresponds to the ammonite *Amaltheus viligaensis* Zone in northeastern Russia (*Resheniya* ..., 1978). Ammonites of the *Tiltoniceras propinquum* Zone occur in the upper part of the *Ogmoconcha longula* Beds of northeastern Russia (Knyazev, 1991). Thus, the *Ogmoconcha longula* ostracod Zone spans the interval from the latest Hettangian to the Earliest Toarcian (up to the ammonite *Tiltoniceras propinquum* Zone), and corresponds to the range that spans from the upper half of the *Meleagrinella subolifex* Beds to the base of the *Dacryomya inflata–Tancredia bicarinata* Zone of the bivalve scale, and from the upper part of the foraminiferal *Trochammina* aff. *sablei* Zone to the *Recurvoides taimyrensis* Zone inclusively.

Nanacythere costata Beds

The index species: Nanacythere costata (Gerke et Lev, 1958).

Representative ostracods: *Ogmoconcha nordvikensis, Ogmoconchella ornata, O. olenekensis, Nanacythere costata,* "*Mandelstamia*" *lubrica,* and "*M.*" *linearis.*

Table 1. Ostracod zonation of the Lower and Middle Jurassic deposits in the North Asian part of Russia correlated with ammonite, bivalve, and foraminiferal zonal scales

Stage	Substage	Ammonite zones (Knyazev *et al.*, 1991; Meledina, 1991)	Bivalve zones (Shurygin, 1987a, 1987b)	Foraminiferal zones (Nikitenko, 1990, 1992)	Ostracod zones and beds
Bathonian	Upper	*A. ? cranocephal.*	*I. isognomonoides*: *Retroceramus vagt*	*Globulina praecircumphlua*	?
	Middle	*A. ishmae*	*Retroceramus bulunensis*		
		A. harlandi	*Retroceramus polaris*		*Camptocythere scrobiculataformis*
	Lower	aff. *greenlandicus*	*Retroceramus retrorsus*		
		A. arcticus			
		Oxycerites jugatus			
Bajocian	Upper	*C. carlsbergensis*		*Riyadhella sibirica*: *Dentalina nordvikiana*	
		C. gracilis		*Lenticulina incurvare, M. pseudoclara*	
		B. borealis	*Retroceramus porrectus*		
	Lower	*Normanites*	*Arctotis lenaensis*: *R. clinatus*	*Riyadhella sibirica*: *Globulina oolithica, Lingulonodosaria nobilissima*	*C. nordvikensis*: *C. praearangastachiensis*
			Solemya strigata		Camptocythere spinulosa
		T. fastigatus	*Retroceramus lucifer*	*Ammodiscus arangastachiensis*	Camptocythere praespinulosa
Aalenian	Upper	*Tugurites whiteavesi*	*Retroceramus* jurensis	*Lenticulina nordvikensis*	
	Lower	*Pseudolioceras maclintocki*	*Retroceramus elegans*	*Astacolus zwetkovi*	*Camptocythere* ex gr. *foveolata*
		P. beyrichi	*Arctotis lenaensis*: *Mclearnia kelimyarensis*	*Verneuilinoides syndascoensis*	
Toarcian	Upper	*Pseudolioceras falcodiscus*	*O. gigantea*: *Arctotis marchaensis*	*Astacolus praefoliaceus, Lenticulina multa*	*Camptocythere* aff. *occalata*
		Pseudolioceras wurttenbergeri			
		P. compactile	*Ps. marchaensis*		*Camptocythere occalata*
	Lower	*Zugodactylites braunianus*	*Meleagrinella faminaestriata*		
		Dactylioceras athieticum	*Dacryomya inflata, Tancredia bicarinata*	*Ammobaculites lobus, Trochammina kisselmani*	*Camptocythere mandeistami*
		H. falcifer			*Trachycythere verrucosa*
		T. propinquum			
Pliensbachian	Upper	*Amaltheus viligaensis*	*Tancredia kuznetsovi*	*Recurvoides taimyrensis*	
		Amaltheus margaritatus	*laevigatus*: *Anradulonectites incertus*	*buliminoides*: *Anmarginulina arctica*	*Nanacythere costata*
		Amaltheus stokesi	*Velata viligaensis*	*Anmarginulina gerkei*	
				T. lapidosa, F. dubiella	
	Lower	?	*Harpax* ex gr. *spinosus*	*Ammodiscus siliceus*	*Ogmoconcha longula*
Sinemurian	Upper		*Otapiria limaeformis*	*Trochammina inusitata, Turritellella volubilis*	
	Lower		*Meleagrinella subolifex*	*Trochammina* aff. *sablei*	
Hettangian	Upper				
	Lower	*P. planorbis*	*Ps. sinuosus*		*Ogmoconcha buurensis*

Boundaries: the lower boundary is at the level where the characteristic ostracod assemblage first appears, the upper corresponds to an abrupt impoverishment of the ostracod assemblage.

The type section is located on the western coast of the Anabar Inlet (Exposure 12, from Member 9 through the lower part of Member 12) and represented by siltstones and silty clays, grey, or dark-grey, about 95 m thick (Levchuk, 1985).

Occurrence: northern Siberia

Age: Specimens of *Amaltheus* cf. *stokesi* are encountered at the base of the *Nanacythere costata* Beds of the type section (*Stratigrafiya ...*, 1976). In the same region, forms of *Amaltheus* sp. ind. are known in the middle part of the ostaracod *Ogmoconcha longula* Zone, and species of *Amaltheus margaritatus* are recognized in the Yuryung-Tumus Peninsula section (Meledina *et al.*, 1987). The upper part of the beds are characterized by bivalve mollusks of the *Tancredia kuznetsovi* Beds known to bear *Amaltheus viligaensis* in northeastern Russia. Correspondingly, the *Nanacythere costata* Beds are assigned to the Late Pliensbachian. They range from the upper part of the *Amaltheus stockei* to the lower part of the *Amaltheus viligaensis* a-zones, or correspond to the interval from the upper part of the *Velata viligaensis* Zone to the upper part of the *Tancredia kuznetsovi* Beds of the bivalve zonation, and to the upper part of the *Tronchammina lapidosa–Frondiculinita dubiella* Zone to the *Anmarginulina arctica* Zone of the foraminiferal scale.

Camptocythere mandelstami Zone

The index species: Camptocythere (*C.*) *mandelstami* Gerke et Lev, 1958.

Representative ostracods (beside the index species): *Trachycythere verrucosa, Kinkelinella* (*Kinkelinella*) *sermoisensis*, and *Polycope pelta*

Boundaries: Camptocythere (*C.*) *mandelstami* first appears at the lower boundary; *Camptocythere* (*C.*) *occalata*, at the upper.

The stratotype is located in eastern Taimyr near Cape Tsvetkov, (Exposure 7, from Member 14, beds 8 - 5, to the lower part of Member 15, beds 4 - 2); and represented by dark-grey, argillite-like silty clays, 32.7 m thick (Levchuk, 1985).

Occurrence: northern Siberia, northeastern Russia, and northwestern Siberia

Age: abubdant *Eleganticeras elegantulum*, *Harpoceras* spp., and *Dactylioceras* spp. occur in the *Camptocythere mandelstami* o-zone in northeastern Russia (Knyazev, 1991). In northern mid-Siberia, the *Camptocythere mandelstami* Zone begins at the base of the Kiterbyut Horizon. Ammonites of the genera *Eleganticeras* are found in the lower parts of the ostracod zone in this region (Suolamskaya Well 26) (Knyazev *et al.*, 1991). The Kiterbyut Horizon clays also correlate to the lower part of the *Dacryomya inflata–Tancredia bicarinata* bivalve zone, the base of which is dated by ammonites *Kolymoceras viluiensis*, *Eleganticeras elegantulum*, and *Harpoceras exaratum* (Kirina, 1966, 1976; Knyazev *et al.*, 1983). Moreover, a belemnite assemblage is encountered at the base of the Kiterbyut Horizon in the area of the Anabar Inlet. suggesting that the horizon lower part is analogues in age to the *Harpoceras falcifer* a-zone (Shurygin, 1978). The upper part of the *Camptocythere mandelstami* o-zone, which encompasses the deposits overlapping the Kiterbyut Horizon, is characterized by the ammonites of *Dactylioceras* ex. gr. *commune* in eastern Taimyr, and in the area of the Anabar Inlet, by *D. commune*, and *D. athleticum*, indicating the *Dactylioceras athleticum* a-zone (*Stratigrafiya ...*, 1976). The upper boundary of the *Camptocythere mandelstami* o-zone is defined by an assemblage renewal and the appearance of *Camptocythere* (*C.*) *occalata*. Still, the first representatives of *Camptocythere* (*C.*) *occalata* were revealed in the studied sections together with *Dactylioceras* spp. Thus, the stratigraphic range of the *Camptocythere mandelstami* o-zone encompasses the *Harpoceras falcifer* and the lower part of the *Dactylioceras athleticum* a-zones, or, according to the bivalve scale, it corresponds to the lower part of the *Dacryomya inflata–Tancredia bicarinata* Zone, whereas in the foraminifer scale it correlates to the *Ammobaculites lobus–Trochammina kisselmani* Zone.

Trachycythere verrucosa Beds

The index species: Trachycythere verrucosa Triebel et Klingler, 1959.

Representative ostracods (beside the index species): the *Camptocythere* (*C.*) *mandelstami*, *Kinkelinella* (*Kinkelinella*) *sermoisensis, Plycope pelta*, and "*Monoceratina vulsa*" (= *M. vulsa*, Riegraf, 1985, p. 89, Table 4, Figs. 25 - 27; non *M. vulsa*, Bate, 1966, p. 400, Table 7, Fig. 5).

Boundaries: the lower boundary is the appearance level of the index species and the accompanying assemblage; the upper is marked by the disappearance of characteristic ostracods.

The type section is located in eastern Taimyr in the area of Cape Tsvetkov (Exposure 7, Member 14, beds 8 - 7) and represented by dark-grey, plastic, silty clays, 19.7 m thick (Levchuk, 1985).

Occurrence: northern mid-Siberia

Age: The Early Toarcian; the *Harpoceras falcifer* and *Dactylioceras athleticum* (lower part) a-zones; the lower part of the *Dacryomya inflata–Tancredia bicarinata* b-zone; and the lower part of the *Ammobaculites lobus–Trochammina kisselmani* f-zone.

Camptocythere occalata Beds

The index species: Camptocythere (*C.*) *occalata* Gerke et Lev, 1958.

Representative ostracods (beside the index species): *Kinkelinella* (*Ektyphocythere*) *debilis*.

Boundaries: the lower boundary indicates the appearance of *Camptocythere* (*C.*) *occalata*; the upper, *Camptocythere* (*C.*) aff. *occalata*.

The type section is located on the western coast of the Anabar Inlet (Exposure 11, Member 15 - the lower parts of Member 17) and represented by interbedding of coarse- to fine-grained siltstone with dark-grey, clayey siltstone, 83.1 m thick (Levchuk, 1985).

Occurrence: northern Siberia, northeastern Russia

Age: In northeastern Russia, the lower part of the *Camptocythere occalata* Beds is characterized by a ammonite assemblage typical of the *Dactylioceras athleticum* and *Zugodactylites monestieri* a-zones (*Stratigrafiya* ..., 1976; Knyazev, 1991). The upper part of the beds contains ammonites characteristic of *Pseudolioceras compactile* and *P. wurttenbergeri* zones (Knyazev, 1991).

Representatives of *Dactylioceras* are encountered in northern mid-Siberia in the lower part of the *Camptocythere occalata* Beds in all the sections studied. The overlying beds are characterized by an occurrence of *Zugodactylites* ex. gr. *braunianus*, corresponding to the *Meleagrinella faminaestriata* b-zone (*Stratigrafiya* ..., 1976; Meledina *et al.*, 1987). The uppermost *Camptocythere occalata* Beds fall within an interval poorly characterized by ammonites and comprising only representatives of the *Pseudolioceras* genus. In the area of the Anabar Inlet, only *Pseudolioceras* sp. ind. (cf. *maclintocki*) found in the talus is referred to this part of the section (*Stratigrafiya* ..., 1976). The upper part of the *Camptocythere occalata* Beds corresponds to the lower part of the *Pseudomytiloides marchaensis* b-zone. In the Vilyui syneclise, *Pseudolioceras alienum* forms are known from this part of the b-zone, but their exact stratigraphic range is unclear. Some specialists attribute the deposits containing these ammonites to the Early Toarcian, while others attribute them to the Early Aalenian (Dagis, 1974; Kirina, 1976). A part of those ammonites was revised as *Pseudolioceras compactile*, and those deposits were dated as the Late Toarcian (Knyazev, 1983). Judging from the aforesaid, we may say that the *Camptocythere occalata* Beds incorporate an upper part of the Lower Toarcian and a lower part of the Upper Toarcian, i.e., the upper parts of the *Dactylioceras athleticum–Pseudolioceras wurttenbergeri* a-zone, and, correspondingly, the upper parts of the *Dacryomya inflata–Tancredia bicarinata* and lower parts of the *Arctotis marchaensis* b-zone, as well as the lower part of the *Astacolus praefoliaceus–Lenticulina multa* Zone of the foraminiferal scale.

Camptocythere aff. occalata Beds

The index species: *Camptocythere* (*C.*) aff. *occalata* Gerke et Lev, 1958.

Representative ostracods: the index species

Boundaries: the lower boundary is at the appearance level of the index species, the upper, at the level where *Camptocythere* (*C.*) ex gr. *foveolata* and the associated ostracod assemblage first appear.

The type section is located in eastern Taimyr, Cape Tsvetkov, (Exposure 5, Member 17) and represented by dark-grey, silty claystones, 37.4 m thick (Levchuk, 1985).

Occurrence: northern mid-Siberia

Age: The *Camptocythere* aff. *occalata* Beds correspond to the upper part of the *Arctotis marchaensis* b-zone characterized by the ammonite species *Pseudolioceras wurttenbergeri, P. falcodiscus*, and *P. beyrichi* in different sections of the Verkhoyansk region, Vilyui syneclise, and northeastern Russia (Knyazev *et al.*, 1991). Thus, the beds range from the Latest Toarcian to the Earliest Aalenian, and, according to the bivalve scale, correspond to the upper part of the *Arctotis marchaensis* Zone, but to the middle part of the *Astacolus praefoliaceus–Lenticulina multa* Zone in the foraminiferal zonation.

Camptocythere ex gr. foveolata Beds

The index species: Camptocythere (*C.*) ex gr. *foveolata* Triebel, 1950.

Representative ostracods: *Orthonotacythere* sp., *Procytherura* ex gr. *multicostata, P.* ex gr. *reticulata*, and *Camptocythere* (*Anabarocythere*) ex gr. *praespinulosa*.

Boundaries: the lower boundary is marked by an appearance of the index species with an accompanying ostracod assemblage; the upper, by an occurrence of *Camptocythere* (*A.*) *praespinulosa* and associated ostracods.

The type section is situated in eastern Taimyr, Cape Tsvetkov, (Exposure 5, the upper part of Member 18, and Member 22) and consists of dark-grey, silty clay with light- and dark-grey, silty clays interbedding with coarse, clayey silts, 84 m thick (Levchuk, 1985).

Occurrence: northern mid-Siberia

Age: The *Camptocythere* ex gr. *foveolata* Beds fall within the section interval nearly barren of ammonites. Therefore, they are dated conventionally by correlation with the b-zone sequence. The lower part of the *Camptocythere* ex gr. *foveolata* Beds corresponds to the lower part of the *Mclearnia kelimyarensis* b-zone, but this position in other sections rich in ammonites is unclear. In northeastern Russia, *Mclearnia kelimyarensis* occurs along with *Tugurites whiteavesi,* whereas in the Verkhoyansk depression it occurs along with *Pseudolioceras maclintocki* (*Stratigrafiya* ..., 1976). Thus, the exact stratigraphic position of the lower part of the *Camptocythere* ex gr. *foveolata* Beds is unclear; they are, at the very least, assumed to be no older than the early Aalenian. Their upper part, which corresponds

to the lower part of the *Retroceramus elegans* b-zone, is dated more exactly. The *Retroceramus elegans* b-zone is characterized by ammonites *Pseudolioceras maclintockin* and *Tugurites whiteavesi* in sections of northeastern Russia and the Verkhoyansk depression (*Stratigrafiya* ..., 1976). Consequently, we accept the proposition that the stratigraphic range of the *Camptocythere* ex gr. *foveolata* Beds corresponds to the Lower Aalenian and the lower part of the Upper Aalenian. In other scales, its range compises the upper part of the *Mclearnia kelimyarensis* and the lower part of the *Retroceramus elegans* b-zones, or the upper part of the *Verneuilinoides syndascoensis* and the lower part of the *Astacolus zwetkovi* f-zones.

Camptocythere praespinulosa Beds

The index species: Camptocythere (*A.*) *praespinulosa* Nikitenko, sp. nov.

Representative ostracods: *Orthonotacythere* sp., *Camptocythere* (*C.*) *nordvikensis*, and *Glyptocythere* ? sp.

Boundaries: the appearance of the index species and the associated ostracod assemblage occurs at the lower boundary, whereas the upper boundary is marked by the renewal of the assemblage.

The type section is located in eastern Taimyr, Cape Tsvetkov, (Exposure 5, members 23 - 24) and is represented by dark-grey, clayey silt, and fine-grained, light-grey siltstone, 49.5 m thick (Levchuk, 1985).

The parastratotype is situated on the western coast of the Anabar Inlet (Exposure 11, members 19 - 22), where it is represented by interbedding light-grey, coarse siltstone and grey, fine-grained, clayey siltstone, 65.4 m thick (Levchuk, 1985).

Occurrence: northern Siberia.

Age: The *Camptocythere praespinulosa* Beds are distinct in sections of eastern Taimyr and the Anabar region. Numerous *Retroceramus jurensis* and *Tugurites whiteavesi* (*Stratigrafiya* ..., 1976), characteristic of the *Tugurites whiteavesi* a-zone in northern Siberia (*Resheniya* ..., 1981), occur in the lower part of the *Camptocythere praespinulosa* Beds. In their upper part, there are abundant *Retroceramus locifer*. Thus, the *Camptocythere praespinulosa* Beds can be assigned to the Latest Aalenian and the Earliest Bajocian; in the bivalve scale; they correspond to the *Retroceramus jurensis* and the lower part of the *Retroceramus lucifer* zones, whereas in the foraminiferal zonation, they correlate to the *Lenticulina nordvikensis* and lower *Ammodiscus arangastachiensis* zones.

Camptocythere nordvikensis Zone

The index species: Camptocythere (*C.*) *nordvikensis* (Sharapova, 1940).

Representative ostracods: *Camptocythere* (*A.*) spp., *Camptocythere* (*C.*) spp., and *Orthonotacythere* spp.

Boundaries: the lower boundary is the appearance level of the index species and an associated ostracod assemblage, the upper boundary is marked by a change in the assemblage.

The stratyotype is situated on the western coast of the Anabar Inlet (Exposure 11, members 22 - 26; Exposure 10, members 27 - 30) and is represented by an interbedding of light-grey, coarse siltstone and grey, clayey, fine siltstone, in the upper part, by dark-gray mudstone, about 200 m thick (*Startigrafiya* ..., 1976).

Occurrence: northern Siberia

Age: The *Camptocythere praespinulosa* o-zone is well characterized by ammonites and retroceramids in eastern Taimyr and in the Anabar region. In the lower part of the zone, numerous *Retroceramus jurensis, R. lucifer, Tugurites whiteavesi,* and *T. fastigatus* (*Stratigrafiya* ..., 1976) occur. These forms are characteristic of the *Tugurites whiteavesi* and *T. fastigatus* a-zones in northern Siberia (*Resheniya* ..., 1981). The upper part of the zone bears *Retroceramus clinatus, Solemya strigata*, and rare *Normatites*. The *Camptocythere praespinulosa* o-zone ranges from the Latest Aalenian to the Early Bajocian, i.e. it includes the upper *Tugurites whiteavesi* and *Normanites* a-zones, and, respectively, the *Retroceramus jurensis* and *Retroceramus clinatis* b-zones, whereas in the foraminiferal scale, its volume corresponds to the *Lenticulina nordvikensis* and the lower *Globulina oolithica–Lingulonodosaria nobilissima* zones.

Camptocythere spinulosa Zone

The index species: Camptocythere (*A.*) *spinulosa* (Sharapova, 1940).

Representative ostracods: *Camptocythere* (*C.*) *nordvikensis, C.* (*C.*) *solida, Orthonotacythere tiberculata, O. shweyeri, Pyrocytheridea* ? sp., *Shuleridea* ? sp., "*Monoceratina*" sp., and *Bairdia* sp.

Boundaries: the lower boundary indicates the appearance of index species and associated ostracods; the upper one, the assemblage change.

The stratotype is situated on the western coast of the Anabar Inlet, (Exposure 10, members 28 - 30) and is represented by dark, clayey siltstone and dark-grey mudstone, about 40 m thick (*Stratigrafiya* ..., 1976).

Occurrence: northern Siberia

Age: Bivalve mollusks *Retroceramus lucifer* are found in the lower part of the *Camptocythere spinulosa* o-zone, whereas its upper part is characterized by numerous *Solemia strigata* and *Retroceramus clinatus* (Meledina *et al.*, 1987; and others). Thus, the zone is assigned to the upper part of the Early Bajocian. According to the bivalve scale it corresponds to the upper *Retroceramus lucifer* Zone and the larger lower part of the *Retroceramus clinatus* Zone, or, to the upper *Ammodiscus arangastachiensis* Zone and lower *Globu-*

lina oolithica–Lingulonodosaria nobilissima zones of the foraminiferal scale.

Camptocythere praearangastachiensis Beds

The index species: Camptocythere (*A.*) *praearangastachiensis* Nikitenko, sp. nov.

Representative ostracods: *Camptocythere* (*C.*) spp., and *Orthonotacythere* spp.

Boundaries: the lower boundary corresponds to the index species appearance, the upper, to the changes in the ostracod assemblage.

The stratotype is situated on Yuryung-Tumus Peninsula, (Exposure 20 "G," the upper part of Member 16), and is represented by dark-grey, fine-fragmented clay, about 25 m thick (Meledina *et al.*, 1987).

Occurrence: northern Siberia

Age: These ostracod beds are characterized by numerous *Retroceramus clinatus* (Meledina *et al.*, 1987) and correspond to the upper part of the Lower Bajocian, i.e., to the *Retroceramus clinatus* b-zone (excluding the *Solemya strigata* b-zone) and to the middle part of the *Globulina oolithuca–Lingulonodosaria nobilissima* Zone of the foraminiferal scale.

Camptocythere arangastachiensis Zone

The index species: *Camptocythere* (*A.*) *arangastachiensis* Nikitenko, sp. nov.

Representative ostracods: *Camptocythere* (*C.*) sp., *Pyrocytheridea* ? sp., and *Paracypris* sp.

Boundaries: the lower boundary is at the appearance level of index species and accompanying ostracods; the upper coincides with the assemblage change.

The stratotype is situated on the western coast of the Anabar Inlet, (Exposure 10, members 31 - 34) and is represented by grey, fragmental siltstone, about 45 m thick (*Startigrafiya* ..., 1976).

Occurrence: northern Siberia

Age: Retyroceramus clinatus forms are encountered in the lower part of the zone, while its higher part are characterized by numerous *Boreicephalites borealis, Cranocephalires* spp., *Retroceramus porrectus*, and *R. retrorsus* (*Stratigrafiya* ..., 1976; Meledina *et al.*, 1987). Therefore, the stratigraphic range of the *Camptocythere arangastachiensis* o-zone is assumed to comprise the upper part of the lower and the upper substages of the Bajocian, i.e., the *Normalites* (uppermost parts) and *Cranocephalites gracilis* a-zones, or the upper part of the *Retroceramus clinatus* and the lower part of the *Retroceramus retrorsus* b-zones, and the upper part of the *Globulina oolithica–Lingulonodosaria nobilissima* Zone with the lower part of the *Globulina praecircumphlua* Zone of foraminiferal zonation.

Camptocythere scrobiculataformis Beds

The index species: Camptocythere (*C.*) *scrobulataformis* Nikitenko, sp. nov.

Representative ostracods: *Pyrocytherides* ? *pura*, and *Paracypris* sp.

Boundaries: the lower and upper boundary is marked, respectively, by the appearance or disappearance of index species and associated ostracods.

The type section is situated in the Yuryung-Tumus Peninsula, (Exposure 19 "G," Member 20) and is represented by greenish-grey, sandy siltstone, about 26 m thick (*Startigrafiya* ..., 1976; Meledina *et al.*, 1987).

Occurrence: northern Siberia

Age: The *Camptocythere scrobiculataformis* beds were dated by the ammonite species *Oxycerites jugatus, Arctocephalites arcticus*, and *A.* aff. *greenlandicus* in sections of the Yuryung-Tumus Peninsula and the Anabar Inlet (*Stratigrafiya* ..., 1976; Meledina *et al.*, 1987), and are of the Early Bathonian age. In other scales, they correspond to intervals of the *Arctocephalites arcticus* and *A.* aff. *greenlandicus* a-zones, the upper part of the *Retroceramus retrosus* and the lower part of the *Retroceramus bulunensis* b- zones, and, to the middle part of the *Globulina praecircumphlua* Zone of foraminiferal zonation.

The described ostracod zones and beds are well traced throughout the vast territory of the northern areas of the Asian and European part of Russia (Lev and Kravets, 1982). Stratigraphic units verified by findings of ammonites and by successions of the bivalve and foraminifer assemblages (Table 2) confirm the above.

THE CIRCUMBOREAL REGIONAL CORRELATION OF THE TOARCIAN, AND OSTRACOD STRATIGRAFIC UNITS

The ostracod assemblages of the Middle Lias of northern Siberia and Western Europe contain such common genera as *Ogmoconcha, Ogmoconchella*, and *Nanacythere*, but usually have no common species, therefore direct correlations of their intervals seem difficult. Still, as has been said, in the lower zone of the Lower Toarcian (the *Tiltoniceras propinquum* a-zone), taxonomic and structural transformations occur in the ostracod assemblages characteristic of sections of northeastern Russia, where the widespread Pliensbachian genera *Ogmoconcha, Ogmoconchella* and others disappear and are not encountered in the overlying deposits and are replaced by representatives of the Progonocytheridae, Trachycutheridae, and other families widely distributed in the higher Toarcian horizons. A similar situation occurs in numerous sections of Western Europe and Canada. Here, in lower parts of the Lower Toarcian deposits, i.e., the *Dactilioceras tenuicostatum* Zone (the analog of the North Asian *Tiltoniceras propinquum* Zone), the presence of both the Pliensbachian (*Ogmoconcha, Ogmoconchella*, and others) and Toarcian ostracods is noted, while the Pliensbachian species

Table 2. Correlated ostracod zonation schemes of the Lower and Middle Jurassic in the North Asian part of Russia

Stage	Sub-stage	Ammonite zones	Zones and beds with ostracods	Eastern Taimyr	Anabar–Nordvik region	Olenek River basin	Vilyui syneclise	Verkhovensk region	Northwestern Siberia	Northeastern Russia
Bathonian	Upper	*C. barnstoni*	?	?	?	?	?	?	?	?
		A.? cranocephal.								
	Middle	*A. ishmae*								
		A. harlandi								
	Lower	aff. *greenlandicus*								
		A. arcticus	*Camptocythere scrobiculataformis*		*Camptocythere scrobiculataformis*	*Camptocythere scrobiculataformis*		*Camptocythere scrobiculataformis*		
		Oxicerites jugatus								
Bajocian	Upper	*C. carlsbergensis*	*Camptocythere arangastachiensis*	*Camptocythere arangastachiensis*	*Camptocythere arangastachiensis*	*Camptocythere arangastachiensis*		*Camptocythere arangastachiensis*	*Camptocythere arangasta-chiensis*	
		C. gracilis								
		B. borealis								
	Lower	*Normanites*	*praearangas-tachiensis*	*Camptocythere spinulosa*	*praearangastach.*	*Camptocythere spinulosa*		*Camptocythere spinulosa*	*Camptocythere spinulosa*	
		T. fastigatus	*Camptocythere spinulosa*	?	*Camptocythere spinulosa*					
Aalenian	Upper	*Tugurites whiteavesi*	*Camptocythere praespinulosa*	*Camptocythere praespinulosa*	*Camptocythere praespinulosa*		*Camptocythere nordvikensis*	*Camptocythere nordvikensis*	*Camptocythere nordvikensis*	
	Lower	*Pseudolioceras* maclintocki	*Camptocythere* ex gr. *foveolata*	*Camptocythere* ex gr. *foveolata*	?	?	? *Camtocythere* ex gr. *foveolata*	*Camptocythere* ex gr. *foveolata*		
		P. beyrichi								
Toarcian	Upper	*Pseudolioceras falcodiscus*	*Camptocythere* aff. *occalata*	*Camptocythere* aff. *occalata*			*Camptocythere* aff. *occalata*	*Camptocythere* aff. *occalata*		
		Pseudolioceras wurttenbergeri								
		P. compactile	*Camptocythere occalata*	*Camptocythere occalata*	*Camptocythere occalata*	*Camptocythere occalata*	*Camptocythere occalata*			*Camptocythere occalata*
	Lower	*Zudodactylites braunianus*								
		Dactylioceras athleticum	*Camptocythere mandelstami*	*C. mandelstami*	*Camptocythere mandelstami*	*Camptocythere mandelstami*	*Camptocythere mandelstami*		*Camptocythere mandelstami*	*Camptocythere mandelstami*
		H. falcifer	*Trachycythere verrucosa*	*Trachycythere verrucosa*						
		T. propinquum		?	?	?	?		?	*Ogmoconcha longula*
Pliensbachian	Upper	*Amaltheus viligaensis*	*Nanacythere costata*	*Nanacythere costata*	*Nanacythere costata*	*Nanacythere costata*	*Nanacythere costata*	*Nanacythere costata*	*Ogmoconcha buurensis*	
		Amaltheus margaritatus								
		Amaltheus stocesi		*O. longula*	*O. longula*	*Ogmoconcha buurensis*	*O. longula*	*O. longula*		
	Lower	?	*Ogmoconcha longula*	?	?		?	?	?	?
Sinemurian	Upper									
	Lower									
Hettangian	Upper									
	Lower	*P. planorbis*	*Ogmoconcha buurensis*			*O. buurensis*				

became nearly extinct at the base of the ammonite *Harpoceras falcifer* Zone (Bate and Coleman, 1975; Riegraf, 1985; Exton and Gradstein, 1984, and others). Thus, this boundary appears to be a good datum level for the correlation of remote sections.

The *Trachycythere verrucosa* Beds are distinguished in the lower part of the *Camptocythere mandelstami* o-zone in Siberia. In the Toarcian deposits of England (Bate and Coleman, 1975), in the *Kinkelinella (Kinkelinella) sermoisensis–K. (K.) intrepida* o-zone, the stratigraphic range of the *Trachycythere verrucosa* and *Kinkelinella (Kinkelinella) sermoisensis* corresponds to the *?Dactylioceras tenuicostatum, Harpoceras falcifer,* and *Dactylioceras commune* (lower part) ammonite zones (Table 3). In the Lower Toarcian deposits of Germany (Riegraf, 1985), in the ostracod *Cytheropteron gwashense* Zone and *Trachycythere verrucosa* Beds, the stratigraphic range of the mentioned species corresponds to a part of the ammonite *Harpoceras falcifer* Zone. The *Trachycythere verrucosa* Beds seem to occur at the base of the Toarcian deposits in the Canadian Arctic Archipelago (Dr. J.H. Wall, personal communication). In Portugal and Canada (the Grand Banks region), in the ostracod *Bairdiacypris* sp. Zone, the stratigraphic range of the *Kinkelinella sermoisensis* species is within the *Harpoceras falcifer* and lower *Hildoceras bifrons* ammonite zones (Exton and Gradstein, 1984). Thus, the *Trachycythere verrucosa* Beds of northern Siberia correspond to the upper part of the ostracod *Kinkelinella (Kinkelinella) sermoisensis–K. (K.) interpida* Zone (England), encompass the ostracod *Cytheropteron gwashense–Trachycythere verrucosa* Zone (Germany), and corresponds to the lower part of the ostracod *Bairdiacypris* sp. Zone (Portugal, Canada, the Grand Banks area) that, according to the ammonite scale, conventionally corresponds to the *Harpoceras falcifer* Zone and, probably, to the lower parts of the *Dactylioceras commune* Zone. Hence, the *Camptocythere mandelstami* Zone corresponds to the upper part of the *Kinkelinella (Kinkelinella) sermoisensis–K. (K.) intrepida* Zone and the *K. (K.) persica* Zone (England), and also to the lower part of the *Bairdiacypris* sp. Zone, which comprises the larger part of it (Portugal and Canada, the Grand Banks area).

In sections of northern Siberia, the ammonites fix the appearance of *Camptocythere (C.) occalata* in the upper part of the ammonite *Dactylioceras athleticum* Zone. *Camptocythere (C.) toarciana*, which I consider to be synonyms of *Camptocythere (C.) occalata*, appears at about the same level (the top of the ammonite *Dactylioceras commune* Zone) in England and Germany (Bate and Coleman, 1975; Riegraf, 1985). The stratigraphic range of *Camptocythere (C.) occalata* (=*C. (C.) toarciana*) in the Western European sections is restricted to the upper part of the Lower and Upper Toarcian deposits, or to the *Peronoceras fibulatum* and *Haugia variabilis* ammonite zones (Riegraf, 1985, p. 24). Thus, the Toarcian stage is most favourable for interregional correlations of ostracod beds because of the mutual invasion of microfauna due to the rise in the eustatic sea level in the Toarcian, the climatic changes,

Table 3. Correlated ostracod zonation schemes of the Toarcian in the North Asian Russia and Western Europe

General stratigraphic scale (Fanerozoi..., 1984)			Ammonite zones in Western Siberia (*Stratigrafiya ...*, 1976; Knyazev *et al.*, 1991)	The North Asian part of Russia	England (Bate and Coleman, 1975)	Southwestern Germany (Riegraf, 1985)
Upper Toarcian	*thoarsense*		*wurttenbergeri*	*C.* aff. *occalata*	?	?
	variabilis		*compactile*	*Camptocythere occalata*		*Praeschuleridea tenera P. aspera*
						Kinkelinella bucki
Lower Toarcian	*bifrons*	*braunianus*	*monestieri*		*Kinkelinella debilis, Campt. toarciana*	*Kinkelinella debilis, Campt. toarciana*
		fibulatum				
		commune	*athleticum*	*Camptocythere mandelstami*	*Kinkelinella persica*	?
	falcifer	*falcifer*	*falcifer*	*Trachycythere verrucosa*	*Kinkelinella sermoisensis. K. intrepida*	
		elegans				*C. gwashense, Trach. verrucosa*
		exaratum				?
		elegantulum				*Kinkelinella knitteri*
	tenuicostatum		*propinquum*	*Ogmoconcha longula*		*M. michelseni K. champeauae*
Upper Pliensbachian	*spinatum*		*viligaensis*		?	*Ogmoconcha ambo, O. impressa*
						Trachycythere tubulosa seratina. O. cincta

and possibly the small latitudinal temperature gradient, unifying environments, and other factors (Table 3).

The correlation of Middle Jurassic ostracod beds has been difficult so far, though there are certain reference levels, for instance, in the Aalenian and Bajocian, which could serve as a base for this type of correlation in the future.

DESCRIPTION OF INDEX SPECIES

Suborder Podocopina Sars, 1866

Family Progonocytheridae Sylvester–Bradley, 1948

Genera Camptocythere Triebel, 1950

Camptocythere: Triebel, 1950; Lev, 1958; *Osnovy Paleontologii* ..., 1960; *Treatise* ..., 1961.

Aparchitocythere: Swain and Peterson, 1952; *Osnovy Paleontologii* ..., 1960; *Treatise* ..., 1961.

The type species: Camptocythere praecox Triebel, 1950; the Lower Aalenian deposits of Germany.

Remarks. When studying the Middle Jurassic *Camptocythere* forms of northern Siberia, two distinct groups of species, *Camptocythere spinulosa* and *C. occalata*, have been recognized, which I attribute, respectively, to the two subgenera *Anabarocythere* and *Camptocythere* proper.

The genus *Aparchitocythere* Swain and Peterson, 1952, seems to be a synonym of the genus *Camptocythere* Triebel, 1950, as it has similar hinge structures, form, position and number of muscle scars, and a carapace form of similar configuration and morphology.

Age and occurrence: the Toarcian, Middle Jurassic of northern Russia, Western Europe, and North America.

Subgenera Camptocythere Triebel, 1950

Camptocythere (Camptocythere) occalata Gerke et Lev, 1958.

Plate 1, Figs. 20 - 22.

Camptocythere mandelstami var. *occalata* Gerke et Lev: Lev, 1958, p. 42, Table 6, Fig. 4.

Camptocythere toarciana Bate et Coleman: Bate and Coleman, 1975, p. 8, Table 2, Figs. 1 - 11; Riegraf, 1985, p. 84, Table 4, Figs. 5 - 6.

Age and occurrence. The Latest Early Toarcian to the Earliest Late Toarcian; the upper *Dactylioceras athleticum* to the *Pseudolioceras wurttenbergeri* a-zones; the upper *Dacryomya inflata–Tancredia bicarinata* to the lower *Arctotis marchaensis* b-zones; the lower part of the foraminiferal *Astacolus praefoliaceus–Lenticulina multa* Zone, the *Camptocythere occalata* Beds of northern Russia; and the *Peronoceras fibulatum* to *Haugia variabilis* a-zones of Western Europe.

Camptocythere (Camptocythere) scrobiculataformis, sp. nov.

Plate 1, Figs. 16 - 19

Name derivation. Scrobiculataformis means similar to *scrobiculata.*

Holotype. Number 1067/16, OIGGiM SO Ross. Akad. Nauk, Yuryung-Tumus Peninsula, Exposure 19, Bed 9, Sample 2; the Early Bathonian, the ammonite *Arctocephalites* aff. *greenlandicus* Zone, the bivalve *Retroceramus polaris* Zone, and the *Camptocythere scrobiculataformis* Beds.

Material. About 10 specimens varying in preservation states.

Diagnosis. The carapace is rounded subrectangular, with a slightly convex dorsal margin. The anterior margin is usually higher than the posterior. The valve surface shows a coarse faveolate sculpture.

Description. The carapace of medium size is rounded, rectangular, even-convex. The dorsal margin is slightly convex. The transition to the anterior margin is continuously rounded, and even toward the posterior margin, but sometimes benched. The ventral margin is straight, sometimes slightly convex, gradually passing into the anterior and posterior margins. The anterior and posterior margins are rounded. A narrow, weakly developed pore canal zone runs along the anterior margin. The left valve is a little larger than the right one, and slightly overlaps it along the dorsal margin. Well developed axial ridges are well pronounced on the ventral margin. The valve surface is covered with a well developed foveo-reticular sculpture.

Carapace dimensions, mm	Length	Height	Thickness	Length/Height ratio
Holotype No 1067/11	0.62	0.40	0.40	1.55
Variation limits	0.43 - 0.71	0.27 - 0.42	0.25 - 0.41	1.50 - 1.69

Comparison. The species differs from *C. (C.) occalata* by its distinct socket-cellular sculpture carapace with a poorly developed pore-canal zone and an evenly convex form.

Age and occurrence: the Early Bathonian; the *Oxycerites jugatus* and the lower *Arctocephalites* aff. *greenlandicus* a-zones; the upper *Rectoceramus retrorsus* and lower *R. polaris* b-zons; the lower *Globulina praecircumphlua* f-zone with *Camptocythere scrobiculataformis* Beds; and the the northern areas of Siberia, and European Russia.

Subgenus Anabarocythere Nikitenko, subgen. nov

The type species: *Camptocythere spinulosa* (Sharapova, 1940); the Early Bajocian, northern Siberia.

Diagnosis. Carapaces are of medium size, rounded-subrectangular, and rounded-subtrapeziform. The rounded node is notable in the middle of the valve, a lit-

tle closer to the antrerior margin. The bar or spine directed toward the posterior margin occurs on the side of each valve, in the posterior-ventral area, closer to the posterior margin. The valve surface has a foveo-reticular sculpture. The hinge structure, form, number, and position of muscle scars are similar to those of other *Camptocythere* forms.

Comparison. The considered subgenus differs from the subgenus *Camptocythere* Triebel, 1950 by nodes on its valve sides and by bars or spines situated in the posterior-ventral area of the carapace.

Representative species: Camptocythere (Anabarocythere) spinulosa, C. (A.) praespinulosa, C. (A.) praearangastachiensis, and *C. (A.) arangastachiensis*.

Age and occurrence: the Middle Jurassic; northern Russia.

Camptocythere (Anabarocythere) praespinulosa, sp. nov.

Plate 1, Figs. 3 - 5

Name derivation. Praespinulosa means that the species preceded *C. (A.) spinulosa*.

Holotype. No 1048/12, OIGG&M SO RAN, Cape Tsvetkova, Exposure 15, Bed 24, Sample 2; Late Aalenian; the *Tugurites fastigatus* a-zone, the *Retroceramus jurensis* b-zone, the *Camptocythere praespinulosa* Beds.

Material. Several dozens of carapaces of various preservation states.

Diagnosis. The carapace is rounded-subrectangular, with a rounded node in the middle of the valves, shifted closer to the anterior margin. The bar directed toward the posterior margin is in the posterior-ventral area on every valve where they have maximal convexity near the posterior margin. The valve surface has a foveo-reticular sculpture.

Description. The carapace has a rounded-rectangular shape and a small cross depression in the center that extends from the dorsal margin to the middle of the valve. The valves are maximum convex near the posterior part of the carapace. The dorsal margin is straight or slightly convex. The transition between the anterior and posterior margins is continuous. The ventral margin is slightly convex, smoothly grading into the anterior and posterior margins. The anterior and posterior margins are rounded and equal in height. A narrow pore canal zone is developed along the anterior margin. The left valve is larger than the right one and overlaps it along the dorsal margin within the upper parts of the anterior and posterior margins. A small rounded node is observed in the middle of the valves, a bit closer to the anterior margin. The small bar extended toward the posterior margin is situated on each valve side, in the posterior-ventral area of maximal convexity near the posterior margin. The valve surface is covered with a foveo-reticular sculpture. Small linear ridges were noted on the ventral margin.

Carapace dimensions, mm	Length	Height	Thickness	Length/Height ratio
Holotype No 1067/11	0.63	0.47	0.40	1.34
Variation limits	0.42 - 0.67	0.22 - 0.50	0.24 - 0.40	1.30 - 1.87

Variability. The socket cellular sculpture and the node in the central part of the valves are variably developed.

Comparison. The species described is similar to *C. (C.) spinulosa* (Sharapova, 1940, p. 126, Table 1, Fig. 6) from the Bajocian deposits of northern Siberia; but differs in its rounded-rectangular carapace with anterior and posterior margins that are equal in height, in a less developed node in the central part of valves, and in the presence of bars in the posterior-ventral area.

Age and occurrence. The Late Aalenian–Earliest Bajocian; the *Retroceramus jurensis* and the lower *R. lucifer* b-zones; the *Lenticulina nordvikensis* and lower *Ammodiscus arangastachiensis* f-zones; and the *Camptocythere praespinulosa* Beds; northern Siberia.

Camptocythere (Anabarocythere) praearangastachiensis, sp. nov.

Plate 1, Fig. 10

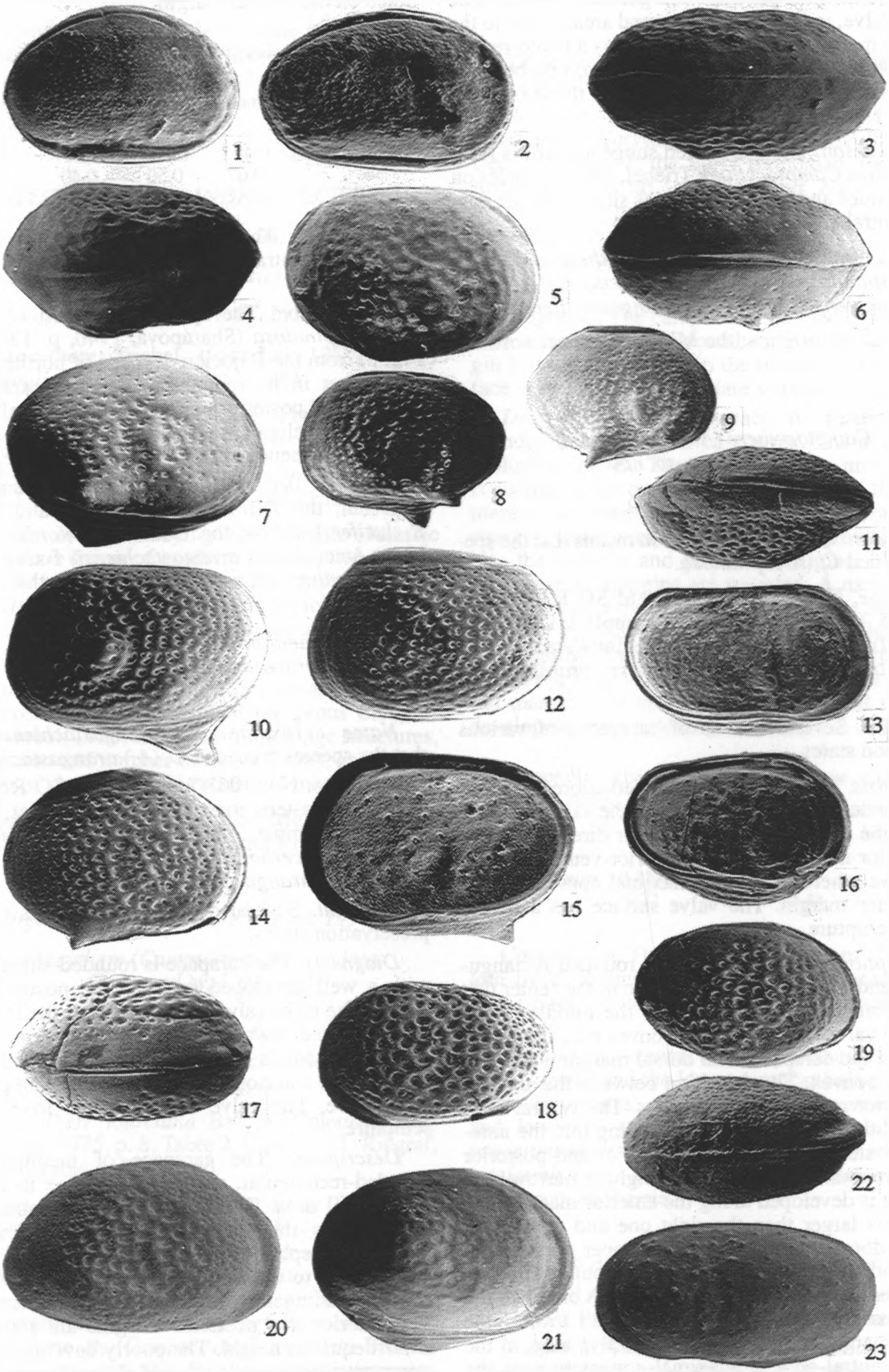
Name derivation. Praearangastachiensis means that the species preceded *C. (A.) arangastachiensis*.

Holotype. No. 1067/7, OIGG&M SO Ross. Akad. Nauk, the western coast of the Anabar Inlet, Exposure 10, Bed 7, Sample 3; the Early Bajocian, the upper part of the *Retroceramus clinatus* b-zone, the *Camptocythere praearangastachiensis* Beds.

Material. Several dozens of carapaces of various preservation states.

Diagnosis. The carapace is rounded-subrectangular with a well developed spine in the posterior-ventral area on the right valve's side, whereas the left one has a bar directed toward the posterior margin. The well developed node is in the middle part of the left valve, closer to the anterior margin; it is less developed on the right valve. The valve surface has a foveo-reticular sculpture.

Description. The carapace of medium size is rounded-rectangular, with a small bulge in the posterior-ventral area. The dorsal margin is straight. The transition to the anterior and posterior margins is smooth and spherical. The ventral margin is straight and parallel to the dorsal one, in some cases slightly convex, grading into the anterior and posterior margins. The anterior and posterior margins are rounded and almost equal in height. The poorly developed and narrow pore canal zone is situated along the anterior margin. The left valve is a little larger than the right one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and has a well developed rounded node closer to the anterior margin; the node of the right valve is less developed. The well developed spine is characteristic of the right valve side being set in the posterior-ventral maximum convex area closer to the posterior margin. The bar on the left valve is oriented toward the posterior margin. Well developed linear ridges are observed on the ventral side. The valve sorface has a well developed foveo-reticular sculpture.

Carapace dimensions, mm	Length	Height	Thickness	Length/Height ratio
Holotype No 1067/11	0.61	0.40	0.33	1.52
Variation limits	0.41 - 0.68	0.30 - 0.42	0.27 - 0.36	1.37 - 1.61

Variability. The node on the right valve is expressed differently.

Remarks and comparison. The species shows features of both *C.* (*A.*) *spinulosa* and *C.* (*A.*) *arangastachiensis*, being intermediate in form. It differs from the first species in that it has no spine on the left valve and a poorly developed node on the right valve; compared to *C.* (*A.*) *arangastachiensis*, it has developed nodes in the middle part of its valves.

Age and occurrence. The Latest Early Bajocian; the upper parts of the *Retroceramus clinatus* b-zone; the upper part of the *Globulina oolithica–Lingulonodosaria nobilissima* f-zone, the *Camptocythere praearangastachiensis* Beds; northern Siberia.

Camptocythere (Anabarocythere) arangastachiensis, sp. nov.

Plate 1, Figs. 11 - 16

Name derivation. The species *arangastachiensis* is named after the Arangastakh Creck on the Yuryung-Tumus Peninsula.

Holotype. No 1067/11, OIGG&M SO Ross. Akad. Nauk, Yuryung-Tumus Peninsula, Exposure 17, Bed 2, Sample 2; the Late Bajocian; the *Boreicephalites borealis* a-zone, the *Camptocythere arangastachiensis* o-zone.

Material. About 30 specimens of various preservation states.

Diagnosis. The rounded-subrectangular carapace has a spine situated in the posterior-ventral area of the right valve and a bar directed toward the posterior margin on the left valve. The valve surface has a foveo-reticulat sculpture.

Description. The carapace of medium size is rounded-rectangular to rounded-subtrapez in form, evenly convex. The dorsal margin is straight, or slightly convex in some cases. The transition to the anterior and posterior margins is gradual. The ventral margin is slightly convex and grades into the anterior and posterior margins. The anterior and posterior margins are rounded. A narrow pore canal zone, developed differently, is set along the anterior margin. The left valve is a little larger than the right one, and in some cases has a slightly developed rounded node in the central part, closer to the anterior margin. The spine is located in the posterior-ventral area of the right valve, where it has maximal convexity and is closer to the posterior margin. On the left valve there is a small bar extending

The Early and Middle Jurassic Ostracods of Northern Siberia

1, 2 – *Ogmoconcha buurensis* sp. nov.: 1 – Holotype No 1067/1, Buur River, Exposure 28, Member 3, Sample 54, Hettangian ? – Early Sinemurian, the *subolifex* Beds, ×50; 2 – Holotype No 1067/2, Buur River, Exposure 35, Member 2, Sample 135, Hettangian, the *planorbis* a-zone, ×55.

3 - 5 - *Camptocythere* (*Anabarocythere*) *praespinulosa* sp. nov.: 3 - Holotype No 1048/13, Eastern Taimyr (Tsvetkov Cape), Exp. 5, Bed 24, Sample 2, Late Aalenian, the *jurensis* b-zone, ×73; 4 - Holotype No 1048/14, ib., id., ×67; 5 – Holotype No 1048/12, ib., id., ×67. 6 - 9 – *Camptocythere* (*Anabarpcythere*) *spinulosa* (Sharapova, 1940): 6 – Holotype No 1067/3, western coast of Anabar Inlet, Exposure 10, Bed 3, Sample 1, Early Bajocian, the *clinatus* b-zone, ×72; 7 – Holotype No 1067/4, ib., id., ×72; 8 – Holotype No 1067/5, ib., Bed 2, Sample 2, id., ×50; 9 – Holotype No 1067/6, Yuryung Tumus Peninsula, Exposure 20, Bed 1, Sample 3, Early Bajocian, the *clinatus* b-zone, ×47.

10 – *Camptocythere* (*Anabarocythere*) *praearangastachiensis* sp. nov., Holotype No 1067/7, western coast of Anabar Inlet, Exposure 10, Bed 7, Sample 3, Early Bajocian, the *clinatus* b-zone, ×72.

11 - 15 – *Camptocythere* (*Anabarocythere*) *arangastachiensis* sp. nov.: 11 – Holotype No 1067/8, Yuryung-Tumus Peninsula, Exposure 17, Bed 3, Sample 2, Late Bajocian, the *borealis* a-zone, ×83; 12 – Holotype No 1067/9, ib., Bed 2, Sample 2, id., 72; 13 – Holotype No 1067/10, ib, id., ×65; 14 – Holotype No 1067/11, ib., id., ×72; 15 – Holotype No 1067/12, Anabar River, Exp. 6, Bed 22, Sample 2, Late Bajocian, the *retrorsus* b-zone, ×83.

16 - 19 – *Camptocythere* (*Camptocythere*) *scrobiculataformis* sp. nov.: 16 – Holotype No 1067/13, Yuryung-Tumus Peninsula, Exp. 19, Bed 8, Sample 2, Early Bajocian, the *arcticus* a-zone, ×55; 17 – Holotype No 1067/14, ib., Exp. 17, Bed 8, Sample 2, id., ×60; 18 – Holotype No 1067/15, ib., Exp. 19, Bed 8, Sample 1, the *jugatus* a-zone, ×88; 19 – Holotype No 1067/16, ib., Bed 9, Sample 2, the aff. *greenlandicus* a-zone, ×60.

20 - 22 – *Camptocythere* (*Camptocythere*) *occalata* Gerke et Lev, 1958: 20 – Holotype No 1048/5, eastern Taimyr (Tsvetkov Cape), Exp. 7, Bed 1, Sample 2, Early Toarcian, the *athleticum* a-zone, ×47; 21 – Holotype No 1067/17, ib., Exp. 5, Bed 3, Sample 2, Late Toarcian, the *marchaensis* b-zone, ×50; 22 – Holotype No 1067/18, Vilyui R., Exp. 18, Bed 12, Early Toarcian, the *athleticum* a-zone, ×66.

23 – *Camptocythere* (*Camptocythere*) *mandelstami* Gerke et Lev, 1958. Holotype No 1048/3, Eastern Taimyr (Tsvetkov Cape), Exp. 7, Bed 7, Sample 2, Kiterbyut Horizon, Early Toarcian, the *lobus–kisselmani* f-zone, ×40.

The collections are stored at the Museum of the Joint Institute of Geology, Geophysics and Mineralogy, Siberian Division, Russian Academy of Sciences, Novosibirsk, under Nos. 1048 and 1067.

toward the posterior margin. Small linear ridges are observed on the ventral margin. The valve surface has a well developed foveo-reticular sculpture.

Carapace dimensions, mm	Length	Height	Thickness	Length/Height ratio
Holotype No 1067/11	0.56	0.38	0.30	1.47
Variation limits	0.38 - 0.70	0.25 - 0.41	0.22 - 0.35	1.45 - 1.70

Variability. The carapace form changes from rounded-subrectangular to rounded-subtrapezoid, which seems related to diamorphism.

Comparison. The species differs from *C. (A.) praespinulosa* in its well developed spine on the right valve and in the lack of nodes in the central part of its valves.

Age and occurrence. The Latest Early Bajocian to the Earliest Bathonian; the upper *Normanites* and lower *Oxycerites jugatus* a-zones; the upper *Retroceramus clinatus* and lower *R. retrorsus* b-zones; the upper *Globulina oolithica–Lingulonodosaria nobilissima* and lower *Globulina praecircumphlua* f-zones; the *Camptocythere arangastachiensis* o-zone; the northern areas of European Russia.

Suborder Metacopina Sylvester–Bradley, 1961

Family Healdiacea Harlton, 1933

Genus Ogmoconcha Triebel, 1941

Ogmoconcha buurensis, sp. nov.

Plate 1, Figures 1, 2.

Name derivation. The species *buurensis* named after the Buur River, northeastern Siberia.

Holotype. No 1067/1, OIGG&M SO Ross. Akad. Nauk, Buur River, Exposure 28, Member 3, Sample 54; the Hettangian, ? Early Sinemurian; the lower part of the *Meleagrinella subolifex* bivalve zone, the *Ogmoconcha buurensis* Beds.

Material. Several well preserved carapaces.

Diagnosis. The carapace is irregularly oval and beanlike. The valve surface has an indistinct foveolate sculpture.

Description. The carapace of medium size is irregularly oval to beanlike in shape, with a maximal bulge in the middle part. The dorsal margin is convex, with a bend in either the middle part or closer to the anterior margin. The transition to the anterior and posterior margins is gradual and wide-rounded. The ventral margin is straight on the left valve but slighly concave on the right valve and grades into the anterior and posterior margins of both valves. The anterior margin is wide and arched; the posterior margin is narrower than the anterior one and blunted. The left valve is larger than the right one, and overlaps it along the dorsal and ventral margins. The valve surface has an indistinct foveolate-sculpture.

Carapace dimensions, mm	Length	Height	Thickness	Length/Height ratio
Holotype No 1067/11	0.76	0.54	0.40	1.41
Variation limits	0.58 - 0.76	0.45 - 0.54	0.35 - 0.40	1.29 - 1.41

Variability. The valves overlap to varying degrees and the foveolate sculpture is variably developed.

Comparison. The species differs from all the known *Ogmoconcha* forms in the foveolate sculpture of its valves.

Age and occurrence. The Hettangian; the *Psiloceras planorbis* a-zone; the lower *Meleagrinella subolifex* Beds; the lower part of the *Trochammina* aff. *sablei* f-zone, the *Ogmoconcha buurensis* Beds; northern Siberia.

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The Permian Radiolarians of Northeastern Russia

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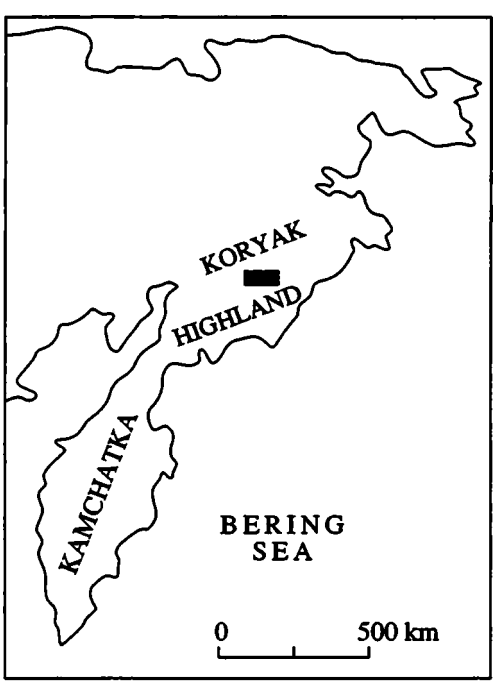
Abstract – The Lower Permian radiolarians from the new locality on the Koryak Highland are described. All of the recovered radiolarians were studied with a scanning electronic microscope; a comparison with known coeval assemblages revealed that they are more similar to the radiolarians of Japan and North America than to the assemblages of the Urals. A new species of the genus *Spinodeflandrella* was named after B.B. Nazarov, the founder of the modern radiolarian school in Russia.

On the territory of Russia, the Permian radiolarians were found in the southern Urals, in Primor'e (the Maritime Area) and on the Koryak Highland (*Prakticheskoe* ..., 1988). The radiolarians of the southern Urals were studied in detail and were described in publications in Russia and abroad (Kozur, 1981; Kozur and Krahl, 1987; Nazarov and Rudenko, 1981; Nazarov and Ormiston, 1985; Amon *et al.*, 1990). In her monograph, Rudenko (1991) gives a description of the Permian radiolarians of Primor'e. However, the radiolarians from the Koryak Highland are seldom mentioned in Russian publications (Bragin *et al.*, 1988; Rudenko, 1991; Bogdanov and Vishnevskaya, 1991; Vishnevskaya, 1992). The global extinction of the Paleozoic radiolarians in the Permian attracted the attention of biologists and paleontologists to the radiolarians of this period. Moreover, the distribution of the Permian radiolarian species within the Circum–Pacific belt is similar to the assemblages of localities located far from each other (the Koryak area, Primor'e, Japan, New Zealand, and Alaska), and the description of the Permian radiolarians from the Koryak Highland thus expands the possibilities of their comparative study and geographic distribution. This information is also important for the stratigraphic subdivision of siliceous beds lacking fossils of other faunal groups (Fig. 1).

The discussion in this paper is based on my study of radiolarian assemblages extracted by treating siliceous rocks with hydrofluoric acid; the rock samples were contributed by Ashurko and Razumnyi of the North Kamchatka Geological Prospecting Expedition of the "Kamchatgeologiya" Operational Association. All of the samples were collected from a series of tectonically crumpled imbricated beds in the Khatyrka fault zone in the upper reaches of the Khatyrka River on the Koryak Highland. Several papers discussing the geological structure of the area and its sections came to conflicting interpretations (Markov *et al.*, 1982, Ruzhentsev *et al.*, 1982; Grigor'ev *et al.*, 1987). The geological map of the Pikas'vayam River basin (scale 1 : 500 000) was prepared for publication by Ashurko and colleagues. Figure 2 is a schematic fragment of this map showing the upper reaches of the Pikas'vayam and Khatyrka rivers. The Permian siliceous and volcanic-siliceous rocks are deposited as imbricated beds or blocks a few hundred meters thick in the serpentinitic melange zone. The Permian radiolarians were recovered earlier from two tectonic blocks. One of them is located 20 km west of the locality under consideration and is composed of lenticular grey-green cherts 75 m thick with a body of



Scale 1 : 25 000 000

Fig. 1. The area and location of the Permian radiolarians in northeastern Russia.

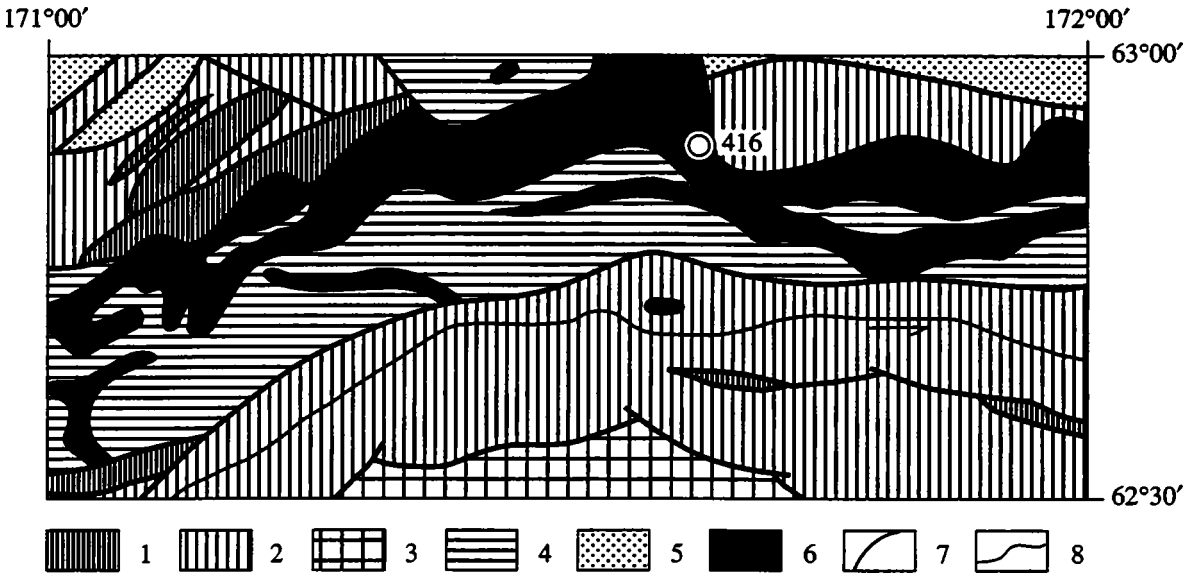
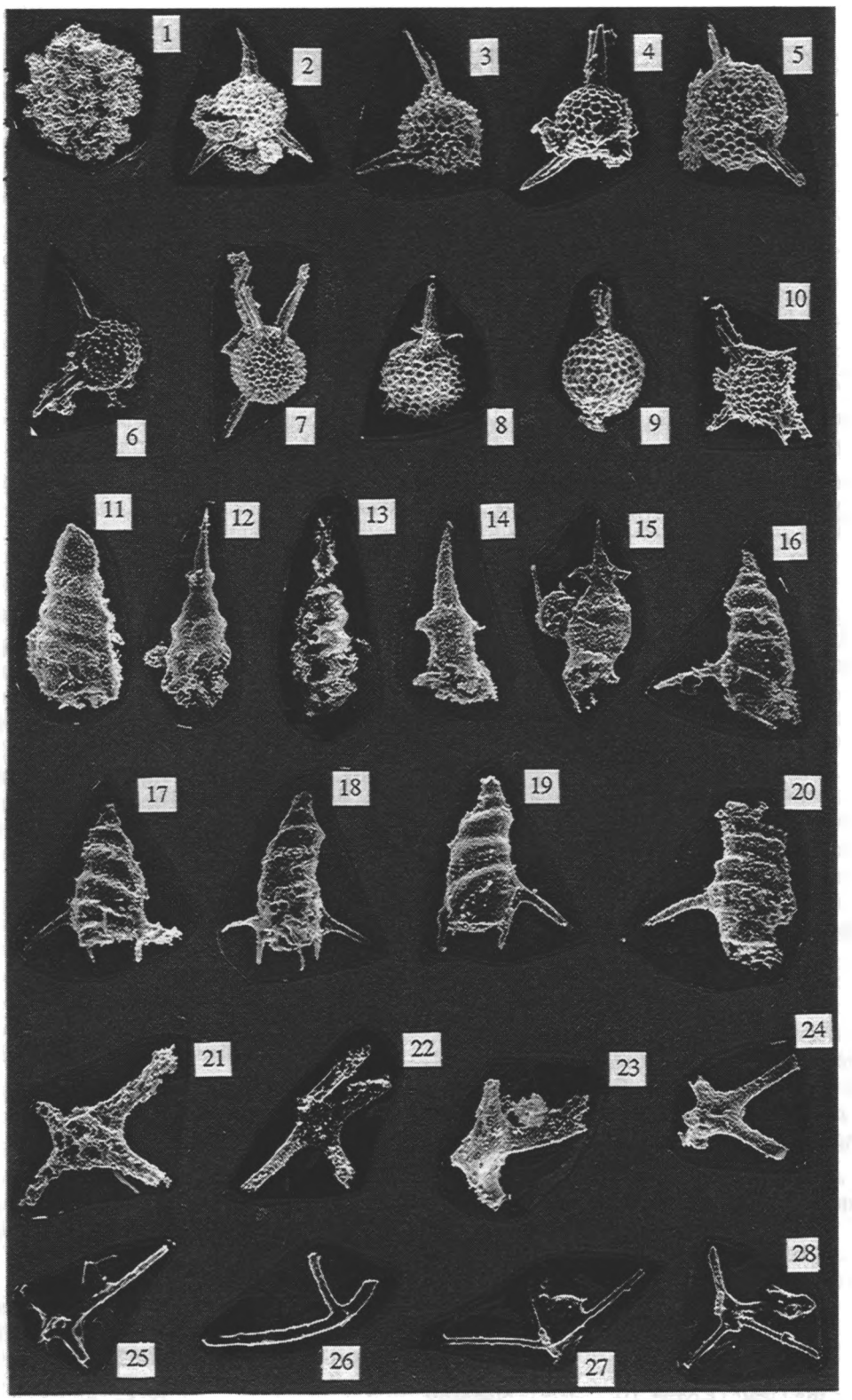


Fig. 2. Schematic representation of the geologic position of the Permian radiolarian-bearing deposits located in the central part of the Koryak Highland area (the basins of the Khatyrka and Pikas'vayam rivers).

1 - 5 – Deposits: 1 – Triassic siliceous; 2 – Jurassic–Lower Cretaceous terrigenous?; 3 – Cretaceous siliceous; 4 – Jurassic–Cretaceous volcanogenic-siliceous-terrigenous; 5 – Upper Cretaceous terrigenous; 6 – serpentinitic melange; 7 – overthrusts; 8 – river; 416 – location of faunal finds.

dolerites 4.5 m thick. The microsections from this locality, studied by Kazintseva of VSEGEI, contain radiolarians resembling the Permian *Pseudoalbaillella*. The other block is located 7 km northwest on the left bank of the Khatyrka River and is composed of grey and brown cherts, in which Bragin of GIN identified *Pseudoalbaillella* and the forms resembling the Late Permian conodonts Razumnyi, (personal communication). The most diverse assemblage of the Permian radiolarians (see Plate) was discovered in outcrop 416 on the right bank of the Khatyrka River (Fig. 2). Because these cherts lack accompanying fauna, the composition of the assemblage of the Paleozoic radiolarians and its age are derived by comparing them with similar radiolarian assemblages from other localities of the world. The typical feature of this assemblage is the abundance of bilateral-symmetrical radiolarians of the Albaillellidae family, which often reach 50%. The most diverse among them are the species of *Spinodeflandrella*, the majority of which are new. The lack of near-apical lateral horns distinguishes them from the species recovered in the area of the Ussuri and Bikin rivers in Primor'e (Rudenko and Panasenko, 1990). In the lower part of the shell, the lateral horns are slim and elegant but not equidimensional. The horn, starting, as a rule, from the upper initial part of the segment, is longer and more massive, whereas the horn completing the last segment is much thinner and shorter. All of the horns, unlike those of *Spinodeflandrella acutata* Rudenko, are rounded. The size of the basal apophyses also varies and their number is usually two, but a few specimens have from three to six apophyses. They are attached one on each side in the symmetry plane and by one in the perpendicular plane, or by two at an angle to it. An important peculiarity of all *Spinodeflandella* from the Koryak Highland is that they do not have more than five segments, the third usually shaped as a slightly prominent wide convolution of the spiral.

Among the polycystines in the assemblage, the Entactiniidae is dominant; the entactinids with a single shell mounted by trihedral horns are the most abundant. There are also numerous representatives of the genus *Triaenosphaera*, and forms resembling *Pluristratoentactinia*. Rather large forms of the genera *Latentifistula* and *Quadriremis* are a specific feature of the assemblage. They are the representatives of the stauraxonous spumellarias group mounted by four or five elongated clavate apophyses with axes oriented in different directions; in several samples they comprise 25 - 30% of the radiolarian assemblage. Among the Latentifistudidae, the forms with oval arms in the distal part prevail. They are very fragile, disintegrate after treatment with hydrofluoric acid and, therefore, could not be fixed on the stage of the scanning electronic microscope. An abundance of large forms of *Hegleria*, a typical Late Permian genus, in this prevalently Early Permian assemblage is noteworthy. This genus was previously found only in the limestones of the Guadalupian Stage of west Texas, USA (Nazarov and Ormiston, 1985). Nazarov, when describing the species *Hegleria mamifera* Nazarov et Ormiston from the Upper Permian rocks of North America, also comments on its geographic occurrence in the Koryak area (*Prakticheskoe* ..., 1988; p. 58). His According to him, the genus *Hegleria* includes only the two Upper Permian species of North America (*Prakticheskoe* ..., 1988). The Early



The Permian radiolarians in the northeast of Russia, the Koryak Highland, the basin of the Khatyrka River.

1 – *Hegleria* sp. *A.*, ×60; 2 - 4 – *Triaenosphaera* cf. *sicarius* Deflandre, ×45, ×50, ×50; 5 – *T.*? *bareillensis* Gourmelon, ×40; 6 - 9 - *T.*? sp., ×40, ×50, ×45, ×60, ×55; 10 – *Pluristratoentactinia*? sp., ×60; 11 – *Albaillella* ex gr. *indensis* Won, ×100; 12, 13 – *A.* sp., ×45, ×50; 14 – *Pseudoalbaillella* sp., ×100; 15 – *P. anfracta* (Nazarov et Rudenko), ×100; 16 - 20 – *Spinodeflandrella nazarovi* sp. nov., ×80, ×100, ×100, ×100, ×200; 21 - 24 – *Quadriremis* sp., ×50, ×50; 25 - 28 – *Palaeoscenidiidae*?, ×50, ×40, ×35, ×30.

The stratigraphic range of radiolarian species

Species of radiolarians	Age						
	Carboniferous	Early Permian				Late Permian	Triassic
		a	s	ar	k		
Hegleria sp.						----------	
Triaenosphaera? *bareillensis* Gourmelon	---------- ?						
Triaenosphaera cf. *sicarius* Deflandre	---------- ?						
Latentifistula sp.		----------					
Quadriremis sp.		----------					
Palaeoscenididae	----------						
Albaillella aff. *apporrecta* Nazarov et Ormiston				---------			
A. permica (Kozur)			----------				
A. ex gr. *indensis* Won	-----						
A. cf. *inferioalata* Nazarov	-----						
Pseudoalbaillella anfracta (Nazarov et Rudenko)				---------			
Haplodiacantus aff. *perforatus* (Kozur)			---------				

Permian dating of the Koryak radiolarians is based on the analysis of the time intervals of typical species (the table). The upper distribution limit of the species *Triaenosphaera*? *bareillensis* Gourmelon and *T.* cf. *sicarius* Deflandre is dated as the Late Carboniferous (Gourmelon, 1986) and, probably, the beginning of the Early Permian. The genera *Latentifistula* and *Quadriremis* belong to the Carboniferous–Permian. The age interval is narrowed by the presence of bilateral-symmetrical radiolarians. For example, the species *Albaillella apporrecta* Nazarov et Ormiston with a basal echinate ring is found only in the Artinskian Stage, whereas the species *A. permica* (Kozur) is confined to the Sakmarian and Artinskian stages of the Lower Permian. Two other species of this genus, *A. indensis* Won and *A. inferiolata* Nazarov, are recorded only from the Upper Carboniferous (Won, 1983; *Prakticheskoe* ..., 1988). The species *Pseudoalbaillella anfracta* (Nazarov et Rudenko) is found just within the Artinskian Stage and *Haplodiacartus perforatus* (Kozur) in the Sakmarian Stage (Panasenko and Rudenko, 1987).

Therefore, all of the detected species indicate that this radiolarian assemblage developed mainly in the Early Permian. Only the genus *Hegleria* indicates the Late Permian, because its lower age limit is the Guadalupian Stage of the Late Permian (Nazarov and Ormiston, 1985).

In Russia, correlative radiolarian assemblages were recorded from the Upper Carboniferous–Lower Permian deposits in the Urals (Kozur, 1980, 1981; Nazarov and Rudenko, 1981; Isakova and Nazarov, 1986) and from the Lower Permian of the Primor'e (Rudenko, 1991). A similar radiolarian assemblage from the western slope of the southern Urals was described by Nazarov in the stratotype section of the upper half of the Sakmarian and Artinskian stages together with conodonts and fusulinas of the *Pseudofusulina verneuili* Zone, i.e., the assemblage containing *Haplodiacanthus perforatus–Helioentactinia ikka*. Unlike the radiolarians of the Urals, the Koryak assemblage lacks spongeous forms of the genera *Tormentum, Copicyntra, Copiellintra*, and stauraxonous *Ruzhencevispongus* typical of the Urals sections, whereas *Helioentactinia* are extremely rare. The composition of the Entactiniidae family is quite different from that found in the southern Urals in the section of the Burtsevskii Horizon on the Sim River (Amon *et al.*, 1990).

A similar radiolarian assemblage with abundant Albaillellidae was described (Ishiga *et al.*, 1982; Kuwahara, 1992) in the Upper Carboniferous–Permian rocks of Japan. More accurate datings were not suggested due to the lack of accompanying fauna in the Japanese sections with the albaillellids of the *Haplodiacanthus* type.

In the Mediterranean province, coeval radiolarian assemblages are also observed. In Sicily (Catalano *et al.*, 1989), the Early Permian is determined by correlation with the complex zone of *Pseudoalbaillella lomentaria* on Ishiga's scale (Ishiga, 1990) and of conodonts *Mesogondolella intermedia* (Igo). If judged by the abundance of *Pseudoalbaillella scalprata* Holdsworth et Jones and *P. elongata* Ishiga et Imoto and the appearance of the first representatives of follicucullids, it seems more likely that this assemblage is younger than the Koryak one, or corresponds to the boundary layers, as do the radiolarian assemblages of Chile (Ling *et al.*, 1985), China, the Philippines, and New Zealand (Murchey and Jones, 1992).

Holdsworth and Jones (1980) described an assemblage from an Alaskan section on the northeastern coast of the USA containing albaillellids and resembling the Koryak assemblage; the age of their assemblage is

approximately the Late Morrowan–Leonardian (the Early Permian).

An impoverished radiolarian assemblage, derived from the Bone Springs Limestones in west Texas, has several characteristic species and genera common to the Koryak assemblage, e.g., *Haplodiacanthus anfractus, Latentifistula,* and *Quadriremis*. The assemblage is dated as the Early Permian according to the presence of Ammonoidea (Nazarov and Ormiston, 1985).

All of the assemblages with *Hegleria mamifera* in the USA (Nazarov and Ormiston, 1985) and in Canada (Harms and Murchey, 1992) were dated as the Late Permian (Leonardian–Guadalupian). It is common knowledge that this time interval on the western margin of North America is the time when the Phosphoria Formation, which contains the phosphate deposits with abundant large monoxonous spicules of siliceous sponges and radiolarians, developed (Murchey and Jones, 1992).

The Guadalupian Stage is actually a time of great mass radiolarian extinction. The Djulfian time corresponds to the period of their lowest taxonomic diversity. The end of the formation of the Koryak radiolarian assemblage probably coincides with the major biotic crisis event of the radiolarians.

A detailed paleontological description of a few typical species from the Lower Permian radiolarian assemblage of the Koryak Highland is given in the Appendix. The radiolarian morphological terminology in this paper is universally used in Russian and foreign publications. The collection of the radiolarians is stored under no. 416 at the Institute of the Lithosphere of the Russian Academy of Sciences.

Order Albaillellaria Deflandre, 1953.

Family Albaillellidae Deflandre, 1953.

Genus Pseudoalbaillella Holdsworth et Jones, 1980.
Pseudoalbaillella anfracta (Nazarov et Rudenko).

Plate, Fig. 15

Holotype. Russia, 1981, Southern Urals, the Lower Permian. Specimen no. 416-2A.

The Koryak Highland, the Permian.

Description. The shell is unperforated, subconic in the apical part, gradually shaping into subcylindric; has two lateral horns growing from the base of the apical cone. The cone narrows towards the terminal end, but the mouth segment is slightly widened.

Dimensions in μm, 3 specimens.The height of the shell is 250 - 300, the diameter of the mouth is 70 - 90, the average length of the horns is 50, the maximal width of the subcylindrical part is 100.

Comparison. Specimen differs from those of the Urals by shorter and thinner horns and by unperforated shell.

Distribution. The lower Permian, the Urals, Primor'e, the Koryak Highland (Russia).

Genus Spinodeflandrella Kozur, 1981.

Spinodeflandrella nazarovi sp. nov. Plate, Figs. 16 - 20.

Holotype. No. 416-2B. Northeastern Russia, the Koryak Highland, the Khatyrka River basin, the Lower Permian. Description. A subconic shell with five tilted segments. In the symmetry plane at the base of the shell, there are lateral horns, one on each side. The horns are rounded, usually inequidimensional, directed apart and slightly downwards. The horn starting from the beginning of the segment is larger than that fixed at the lower part of the segment, The apical cone, as also the subsequent parts, is slightly shifted from central axis, if the specimen is viewed in the symmetry plane. The mouth of the shell is open and has two sharp short basal apophyses, one on each side of the shell. The last segment has thinner apophyses (up to three).

Dimensions in μm, 5 specimen. Total height of the shell is 250 - 270, the diameter of the mouth is 70 - 80, the maximal length of the lateral horns at the base is 100, the minimal length is 50, the length of the basal apophyses is 25 - 30, the height of the apical horn is 30 - 50, the height of the apical cone is 70 - 100, the diameter at the base of the apical cone is 30 - 40. Comparison. Specimen differs from *Spinodeflandrella acutata* Rudenko (1990) and *Albaillella permica* (Kozur) by the shape of the shell, a lesser number of segments, a lack of daggerlike lateral horns and crests with spinules on basal apophyses; it differs from *S. bicornuta* Rudenko et Panasenko (1990) by having one apical apex and rounded lateral horns; it differs from *Albaillella triangularis* Ishiga, Kito et Imoto (1982) from the upper Permian of Japan and Primor'e by the subpyramidal-conic outline and a lack of echinate crest.

Distribution. The Lower Permian, the Koryak Highland, Russia.

Derivation of name. The species is named in honour of B.B. Nazarov, the founder of the modern of radiolarian school in Russia.

Reviewer: A.Yu. Rozanov

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Evolution of the biosphere

Diversity of the Cretaceous Platanoid Plants of the Anadyr'–Koryak Subregion in Relation to Climatic Changes

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Abstract – The dynamics of diversity of the platanoid plants in the Cretaceous of the Anadyr'–Koryak Subregion, northeastern Russia, are analyzed. They include 17 species of the *Platanus, Arthollia, Paraprotophyllum,* and *Pseudoprotophyllum* genera. The platanoid plants first appeared in the Late Albian–Cenomanian, being represented by a single species of the genus *Platanus*. Their diversification peaked in the Turonian–Coniacian, decreased significantly in the Santonian–Middle Maestrichtian, and increased slightly again at the end of the Maestrichtian. The platanoid plants spread throughout this area, which occupied a near-polar position in the Late Cretaceous. This is due to the warm and humid climate and the high latitude solar light regime: a long daylight duration and comparatively weak and diffuse light during the summer growth period. A climate aridization is established for the Cenomanian, Santonian–Early Campanian, and Early Maestrichtian in northern Siberia. This was accompanied by relative warmings in the Cenomanian and Santonain–Early Campanian. At high latitudes these climatic conditions probably caused reduced cloudiness and an increase in direct solar radiation. These processes had an unfavorable effect on broad-leaved platanoid plants. A new species *Platanus louravetlanica* sp. nov. is described from the Upper Albian–Cenomanian of the right bank of the Anadyr' River.

INTRODUCTION

The Late Cretaceous fossil floras are widespread in the Arctic areas of Asia and North America (Fig. 1). As a rule, these floras consist of (1) cryptogamous plants (liverworts, sphenopterids, and ferns), (2) Caytoniales (*Sagenopteris*), (3) cycadophytes (*Cycadites, Nilssonia, Pterophyllum, Encephalartopsis*, and others), (4) Ginkgoales (*Ginkgo, Baiera, Sphenobaiera,* and *Pseudotorellia*), (5) Czekanowskiales (*Phoenicopsis*), (6) deciduous shoot-dropping conifers (*Cephalotaxopsis, Taxites, Elatocladus, Metasequoia,* "*Sequoia*," and others), (7) most probably evergreen conifers with small scale-like leaves (*Pagiophyllum*, cf. *Sequoia ambigua* Heer) and those with rigid hooklike leaves (*Araucarites*, cf. *Sequoia reichenbachii* (Gein.) Heer), and (8) angiosperms that include both broad-leaved forms that commonly dominated the Arctic floras and plants with medium- and small-sized leaves.

Most of the plants comprising the Late Cretaceous near-polar floras were deciduous. Only some conifers and possibly cycadophytes were evergreen. All or a part of them were very likely deciduous (Spicer and Parrish, 1986): the Cretaceous cycadophytes, which were much more abundant and diverse than the living evergreen cycads, were of a much broader adaptive range and included forms that had adapted to the polar latitudes. No documented evergreen modern taxa and allied forms are present among the angiosperms that comprise the Cretaceous Arctic floras. This implies that these plants were deciduous. Taphonomic signatures support this suggestion: many localities show leaf accumulations on bedding planes. Vakhrameev considered the latter as "... a buried defoliation', i.e., the leaves that were shed ... at the end of the growth season" (Vakhrameev, 1988). The suggestion that the plants that comprise these floras were deciduous is supported by the fact that leaves of different plants from many localities have no signs of decomposition and transportation before the burial, i.e., all the leaves were nearly simultaneously shed at the end of the growth season and were rapidly covered with sediment (Spicer *et al.*, 1992).

The Late Cretaceous arctic angiosperms were dominated by forms having broad leaves with toothed margins. As a rule, the plants with lobed and entire-margined leaves were rare. The occurrence of broad-leaved deciduous forests or mixed deciduous broad-leaved and coniferous forests in the Late Cretaceous northward up to 75 - 80°N (Fig. 1) cannot be explained in terms of modern climatic conditions, since present the analogous forests do not northward of 50 - 55°N

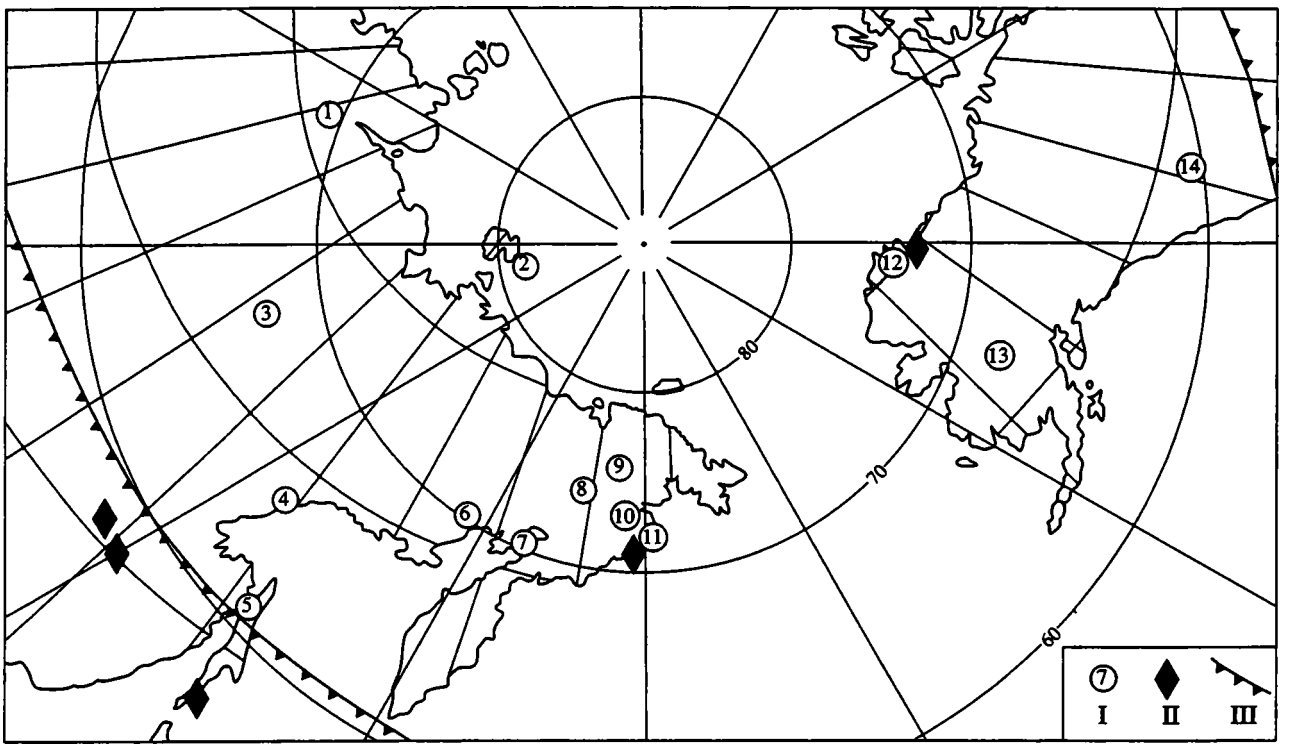


Fig. 1. Reconstructed position of the continents in the middle of the Late Cretaceous (Smith *et al.*, 1981); main localities of the Late Cretaceous broad-leaved floras (I) and dinosaur remains (II); boundary between the warm-temperate and subtropical phytoclimatic zones (III) (after Vakhrameev, 1978 (with supplements).

in Asia and North America (Berg, 1927; Wolfe, 1987). The global climate, which was warmer in the Cretaceous than in the recent times, greatly affected the distribution of vegetation forms (Vakhrameev, 1988; Krassilov, 1985; Krassilov, 1981). Deciduous broad-leaved forests occurring at high latitudes of the Arctic is a specific feature of the Cretaceous vegetation.

DYNAMICS OF DIVERSITY OF THE CRETACEOUS PLATANOID PLANTS OF THE ANADYR'–KORYAK SUBREGION

The broad-leaved component of the Late Cretaceous Arctic floras of Asia and North America consists of platanoid plants and some other taxa of dicots; the former being most abundant and diverse. Evolution of the platanoid plants in the Cretaceous is well demonstrated by the fossil floras of the Anadyr'–Koryak Subregion (Fig. 2). Six stages of the Late Cretaceous flora evolution (Herman, 1993a), the Grebenka (Late Albian–?Early Turonian), Penzhina (Turonian, excluding its beginning), Kaivayam (Coniacian), Barykov [Santonian–Early (?Middle) Campanian], Gornaya Rechka (?Late Campanian–Middle Maestrichtian), and Koryak (Late Maestrichtian ?Danian) have been established for this subregion, which includes northern Kamchatka, the Koryak Highland, the Middle and Lower Anadyr' River basin, and the Pekul'nei Range.

The platanoid plants first appeared in the Grebenka flora (Fig. 2) and were represented by a single species of *Platanus* described below. These plants do not dominate the floral assemblages but their remains are common in the localities. The only locality at the Grebenka River shows abundant leaf imprints of *Platanus*, which formed "fossil leaf accumulations" (Shchepetov *et al.*, 1992). The Grebenka taphoflora also includes *Platanus* sp. and Platanaceae gen. indet leaves, which cannot possibly belong to this species.

The composition of the Penzhina flora is determined by the dominant platanoid plants represented by the following genera: *Platanus* (three species, *P. newberryana* Heer and *P. primaeva* Lesquereux are most abundant), *Arthollia* (two species, *A. pacifica* Herman is a dominant), and *Paraprotophyllum* (two species, *P. ignatianum* (Krysht. et Baik.) Herman occurs most frequently). The Kaivayam flora is also distinguished by dominant platanoid plants, but *Platanus* decreases in diversity (two species), *Arthollia* (two species) and *Paraprotophyllum* (two species) occur frequently, and *Pseudoprotophyllum* (one species) first appears. Thus, the platanoid plants are most diverse (4 genera, 11 species) in the Penzhina and Kaivayam floras. Their leaf remains prevail in the localities comprised of "fossil leaf accumulations," thus determining specific aspects of the taphofloras (Herman and Lebedev, 1991).

The Barykov flora differs from the previous ones in that it is far less diverse and is rich in platanoid plants. The Valizhgen taphoflora of the Santonian (Herman and Lebedev, 1991) contains rare remains of single species of *Platanus*. The Upper Bystraya and Barykov

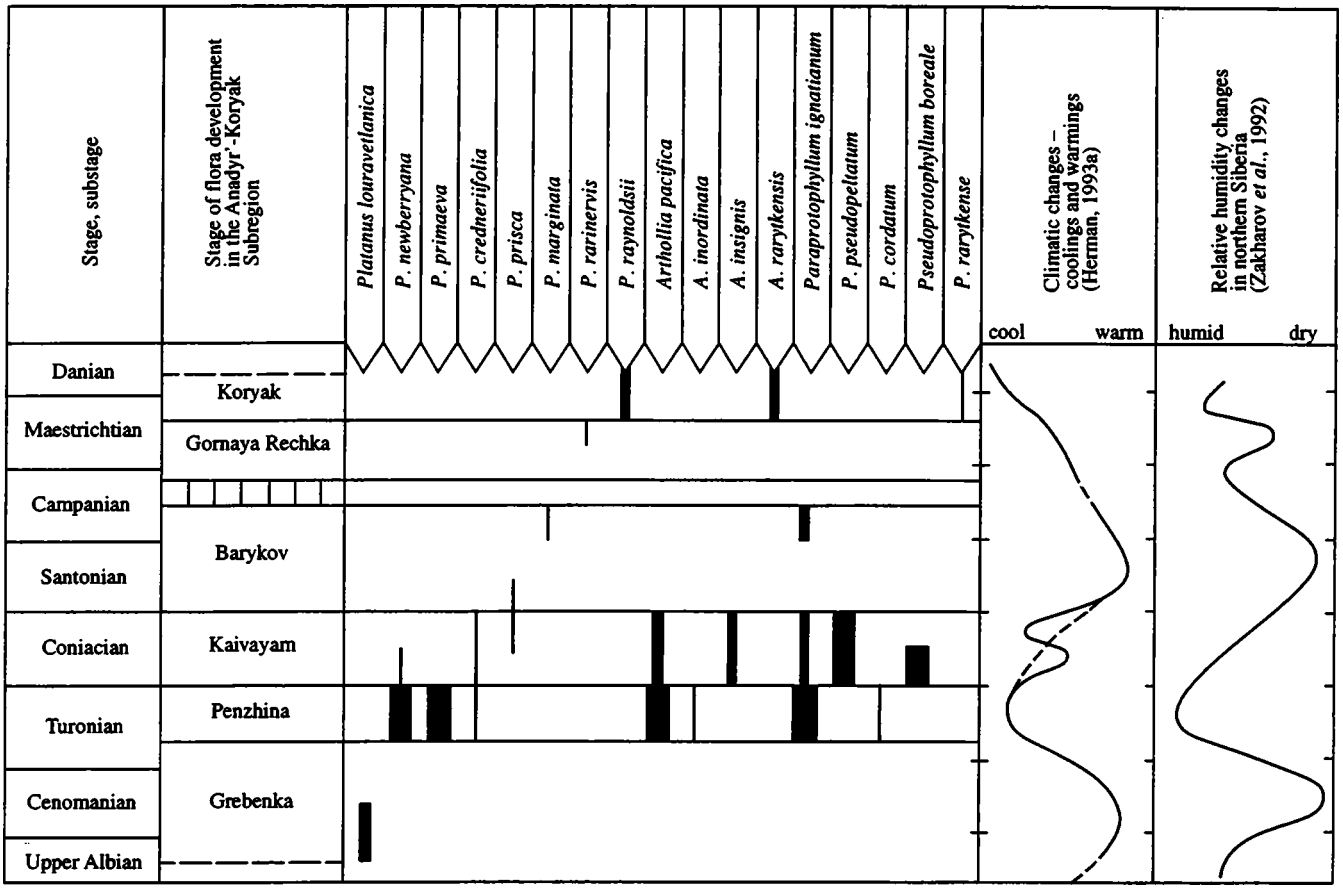


Fig. 2. Distribution and abundance of the Late Cretaceous platanoid angiosperms in the Anadyr'–Koryak Subregion and the Cretaceous climatic changes in northeastern Asia. The thickness of the lines denoting the plant distribution is proportional to the occurrence (dominating, frequent, or rare) of the plants in the taphofloras of the corresponding stages.

taphofloras of the Early (Middle?) Campanian (Herman and Lebedev, 1991) show sporadic occurrences of a single species of *Platanus* and more frequent occurrence of a single species of *Paraprotophyllum*. The Gornaya Rechka flora contains a single species of *Platanus* (Golovneva, 1990), but the platanoid plants may be more diverse in this inadequately studied flora (Golovneva, personal communication).

In the Koryak flora, the diversity and abundance of the platanoid plants again increases, but not as much as in the Penzhina and Kaivayam floras: single species of *Platanus, Arthollia,* and *Pseudoprotophyllum* genera are found there. They are not dominant there (Golovneva, 1990; Golovneva and Herman, 1992; Herman, 1993b).

Thus, the Late Cretaceous platanoid plants of the Anadyr'–Koryak Subregion are represented by 17 species of 4 genera (Fig. 3). *Platanus*, the most diverse genus, consists of 8 species. The Grebenka flora contains a single species of *Platanus*, each of the Penzhina and Kaivayam floras includes three species (two species are dominant in the Penzhina floral assemblages) (Fig. 2). Rare remains of two species of *Platanus* from the Barykov flora and a single species from the Gornaya Rechka flora are known. One species of *Platanus* is common in the Koryak flora, being a subdominant in some localities (Herman, 1993b).

The genus *Arthollia* consists of 4 species (Fig. 3). Two species are known from each of the Penzhina and Kaivayam floras. Except for *A. inordata* (Hollick) Herman, they occur there in abundance. No plants having *Arthollia* leaves have been found in the Barykov and Gornaya Rechka floras. The Koryak flora contains numerous imprints of single species (Herman and Golovneva, 1988).

The genus *Paraprotophyllum*, which includes three species (Fig. 3), is most diverse and abundant in the Penzhina (two species) and Kaivayam (two species) floras, being a dominant or subdominant there. A sole species of *Paraprotophyllum* occurs sporadically in the Barykov flora (the Upper Bystraya and Barykov taphofloras) (Herman and Lebedev, 1991).

The genus *Pseudoprotophyllum* is represented by two species (Fig. 3). It first appears in the Kaivayam flora (the Tyl'pegyrgynai taphoflora from the Pekul'nei Range), being common in some localities and absent in others (Terekhova and Filippova, 1984). This genus has not been found in the Barykov and Gornaya Rechka floras. The only imprint of *Pseudoprotophyllum* is

known from the Koryak flora (Budantsev, 1975), but it may belong to an aberrant (with peltate base) specimen of *Arthollia rarytkense* Golovn., which occurs frequently in this locality. The low abundance and diversity of the genus *Pseudoprotophyllum* in the Cretaceous of the Anadyr'–Koryak Subregion suggest that it originated in North America and migrated via the Bering Strait Land from Alaska and western Canada, where this genus was abundant in the Cretaceous (mainly Cenomanian) floras (Hollick, 1930; Bell, 1963).

Thus, in the Anadyr'–Koryak Subregion, the platanoid plants, which first appeared in the Late Albian–Cenomanian, were most abundant and diverse in the Turonian and Coniacian. Their diversity and abundance decreased significantly in the taphofloras of the Santonian–Middle Maestrichtian and increased again, although not as considerably, towards the end of the Cretaceous.

In addition to platanoid plants, angiosperms of some other taxa had large-sized leaves and were often dominant or subdominant components of the Late Cretaceous arctic floras. Such plants are *Menispermites*, *Trochodendroides*, *Corylites*, *Rarytkinia*, "*Pterospermites*," *Grewiopsis*, and others.

The Late Cretaceous Arctic angiosperms were characterized by a large absolute leaf size and a broad range of variability of the latter (Herman, 1990; Spicer *et al.*, 1992). So, a length of the leaf of *Paraprotophyllum ignatianum* (Krysht. et Baik.) Herman from the Turonian of northwestern Kamchatka varied from 3.3 cm to nearly 50 cm (Herman, 1984, 1990). The width and shape of the leaf, number of secondary veins, and basal vein branches varied correspondingly. This leaf polymorphism causes frequent taxonomic misinterpretations, which can be avoided by thorough study of monotopic selections and by a comprehensive collection of fossil leaves.

To understand how the Cretaceous broad-leaved angiosperms might have advanced so far northward and to explain their variable diversity and abundance in the floras as well as their morphological features (large-sized leaves along with the great range of leaf size), it is necessary to reconstruct the climatic environments that these plants experienced.

THE CLIMATE OF THE NORTHERN HIGH-LATITUDE AREAS IN THE LATE CRETACEOUS

(1) *Temperature.* In the Late Cretaceous the northern high-latitude areas of Asia and North America belonged to a warm-temperate phytoclimatic zone (Vakhrameev, 1978, 1988). The zone is marked by a distribution of fossil plants characteristic of this type of climate (various ferns, deciduous and shoot-dropping conifers, and angiosperms having thin leaf laminas with toothed margins and pinnate venation) and a lack of subtropical plants (tree ferns, palms, and others) (Fig. 1). In the Arctic areas, pycnoxylic tree trunks occur in abundance; trees with pycnoxylic wood are frost resistant.

Having studied fossil leaves, woods, spores and pollen from the Upper Cretaceous (the Upper Albian to Maestrichtian) deposits of northern Alaska, Parrish and Spicer (Parrish and Spicer, 1988; Spicer *et al.*, 1992) estimated the approximate paleotemperatures for this time interval. According to this data, in the Latest Albian and Cenomanian the average annual temperature was approximately 10 ± 3°C, in the Coniacian this temperature may be 2 - 3°C higher but no higher than 13°C. It should be noted, however, that only a small part of the Coniacian deposits in northern Alaska are characterized by paleobotanical records. In the Campanian–Maestrichtian, the average annual temperature. was about 2 - 8°C.

In my previous work (Herman, 1993a), I assessed the relative temperature changes (cooling and warming without quantitative estimates of average annual temperature) from the composition of the Late Cretaceous flora of the Anadyr'–Koryak Subregion. These studies revealed the following climatic events (Fig. 2): a warming in the Late Albian–Cenomanian with corresponding Grebenka flora; a cooling in the Turonian and Coniacian, when the Penzhina and Kaivayam floras existed, whose peak probably occurred in the Turonian; a subsequent considerable warming in the Santonian and Early Campanian with the corresponding Barykov flora, whose peak was in the Santonian; and a cooling towards the end of the Cretaceous, when the Gornaya Rechka and Koryak floras existed.

The Late Cretaceous paleotemperature variations at the middle and high latitudes of Siberia were derived from the isotopic analysis of biogenic carbonates as well as from the paleoecology of marine invertebrates and paleobotanic and lithological data (Zakharov *et al.*, 1992; Zakharov, personal communication). According to isotopic analysis, the minimum average annual temperature (approximately 15°C) occurred near the Cenomanian–Turonian boundary and at the end of the Maestrichtian, the maximum ones occured at the Cenomanian (approximately 17°C) and the Santonian (16°C). Paleontological and lithological data indicate a climatic maximum in the second half of the Cenomanian and in the Santonian, a climatic minimum at the beginning of the Cenomanian and the Turonian–Coniacian, and a cooling towards the end of the Cretaceous.

(2) *Seasonal temperature fluctuations.* The Late Cretaceous wood fossils with distinct annual rings are widespread in northern Asia and Alaska (Spicer *et al.*, 1992). I collected these wood fossils, which probably belonged to gymnosperms from the Cenomanian deposits, at the Grebenka River (the Anadyr' River basin) and at Ugol'naya Bay. These samples indicate the seasonal nature of the plant growth, which may be due to cool winter temperatures. On the other hand, the occurrence of sub-zero temperatures lasting weeks and months is doubtful, because there no solid evidence of the Upper Cretaceous glasiomarine deposits in northern Asia and North America was observed (Epshtein, 1977;

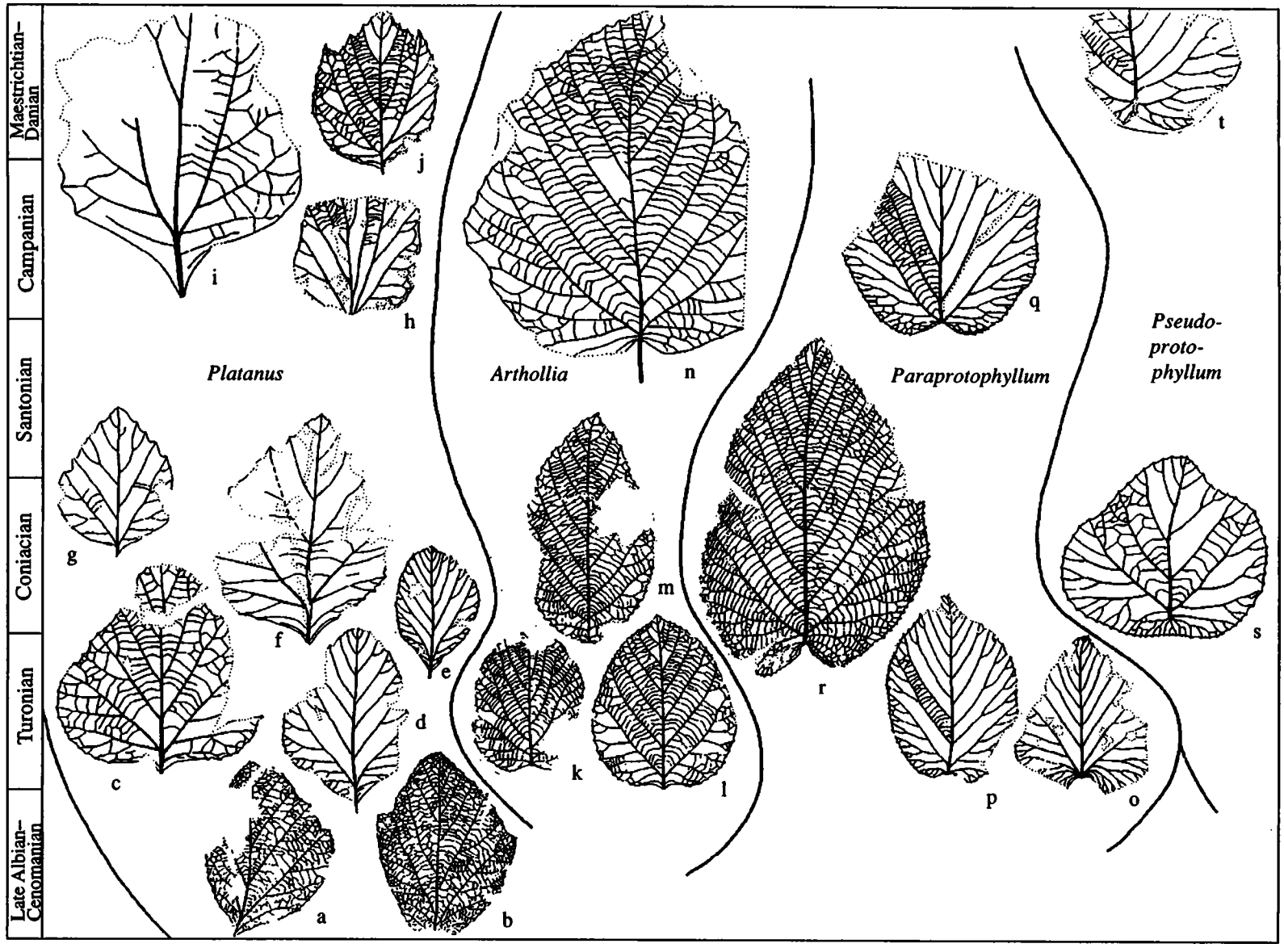


Fig. 3. Diversity of the Late Cretaceous platanoid plants of the Anadyr'–Koryak Subregion.

a, b – *Platanus louravetlanica* Herman et Shczepetov, sp. nov., c – *P. primaeva* Lesquereux, d, e – *P. newberryana* Heer, f – *P. credneriifolia* Budantsev, g – *P. prisca* Herman, h – *P. marginata* (Lesquerreux) Heer, i – *P. rarinervis* Golovn., j – *P. raynoldsii* Newberry, k – *Arthollia inordinata* (Hollick) Herman, l – *A. pacifica* Herman, m – *A. insignis* Herman, n – *A. rarytkensis* Golovn., o – *Paraprotophyllum cordatum* (Samylina) Samylina, p, q – *P. ignatianum* (Krysht. et Baik.) Herman, r – *P. pseudopeltatum* Herman, s – *Pseudoprotophyllum boreale* (Dawson) Hollick (reconstruction of a leaf), t – *P. rarytkense* Budantsev.

Chumakov, 1981; Frakes and Francis, 1988). According to Spicer's personal communication, Upper Cretaceous glaciomarine deposits may be present in northern Alaska.

Analysis of the Cretaceous flora of northern Alaska suggests that in the Cenomanian the warmest average monthly temperature exceeded 20°C and that the winter temperature cooled to 0°C (Spicer *et al.*, 1992). At the end of the Cretaceous (Late Campanian–Maestrichtian) the summer was cooler and the average monthly temperature varied between 10 - 12°C for the warmest month and 2 - 4°C for the coldest one (Brouwers *et al.*, 1987). In the winter, sub-zero temperatures may have occurred, though it is unlikely that these temperature periods lasted weeks or months.

Numerous dinosaur remains were found in the Upper Campanian–Lower Maestrichtian deposits of northern Alaska and in the Middle Maestrichtian of Chukotka (the Lake Pekul'neiskoe area) (Nesov and Golovneva, 1990; Brouwers *et al.*, 1987) (Fig. 1). These remains belong to large (up to 9 - 10 m in length) and small herbivorous hadrosaurids (the Lambeosaurinae subfamily) and carnivorous tyrannosaurids and troodontids. The occurrence of young hadrosaurid bones in the localities far from the areas, where the evergreen subtropical plants existed in the Late Cretaceous (Fig. 1), suggests that at high latitudes these animals were yearround residents who did not migrate south, and whose hibernation was at a reduced level of activity (Brouwers *et al.*, 1987). Studying the Chukotka dinosaurs (Nesov and Golovneva, 1990), Nesov proposed that the presence of young hadrosaurids and small carnivorous dinosaurs argued in favor of a decrease in winter temperature to approximately 0°C. The summer temperature should have been high enough for dinosaur egg incubation. On the other hand, it has been suggested (Currie, 1989; Spicer, personal communication) that the dinosaurs whose remains were found at the polar latitudes were capable of seasonal long-distance migrations at a high speed. The taxonomic similarity between the dinosaur faunas from northern Alaska and Chukotka may also indicate that these animals were capable of migrating a long distance and also an exchange of dinosaur fauna between the above regions.

It is worth noting that the northernmost find of the Late Cretaceous dinosaur bones (Fig. 1) is confined to the North Pacific refugium, which limits the expansion of the contemporaneous cycadophytes (Vakhrameev, 1981, 1988). According to Vakhrameev (1978), the survival of these plants in the refugium can be attributed to a milder and more humid maritime climate with warm winters in this area. Perhaps, the same conditions produced the dinosaur expansion during the Late Cretaceous in the North Pacific refugium. Krasilov (1981) suggested that the Cretaceous dinosaurs may be trophically connected to cycadophyte shrubs and fern marshes capable of supporting large populations of herbivores.

Thus, there is little reason to assume that cold winters with substantial periods of subfreezing conditions in the Late Cretaceous near-polar regions occupied by the deciduous broad-leaved forests existed. On the other hand, the 2 - 4 month-long and light deficient winter might have cooled the Earth's surface and air at the high latitudes, with temperatures being close to 0°C or sometimes lower even in the warmest periods of the Late Cretaceous. The average monthly temperature in summer probably exceeded 10 - 12°C and sometimes 20°C.

(3) *Climate humidity.* Northeastern Asia and northern North America belong to the north humid zone (Vakhrameev, 1978, 1988), as indicated by widespread Cretaceous coal deposits there. Although there are some records of coal in the arid zone (Golbert, 1987), the lack of rocks indicating an arid climate (red deposits, gypsum, salts) in the region under consideration suggests that the climate was humid there in the Late Cretaceous. Paleobotanical data also supports this conclusion: the fossil plants of this zone are devoid of xeromorphic features (narrow and rigid leaves, thick cuticle, and downy leaves). According to Vakhrameev (1978), the survival of the relict mesophytic cycadophytes during the Late Cretaceous in the North Pacific can be attributed to the humid climate and relatively warm winters of this region. Absence of these plants from the Upper Cretaceous deposits in Siberia is possible evidence of an arid climate with a wider temperature range. Broad-leaved angiosperms, characteristic of the Arctic areas, probably existed only under the conditions of significant air and soil humidity that limited intensive leaf transpiration.

The paleobotanical and sedimentological data from Siberia (Zakharov *et al.*, 1992; Zakharov, personal communication) records relatively arid episodes in the Middle Cenomanian, Santonian–Campanian, and Early Maestrichtian, while relatively humid episodes were recorded in the Turonian and the Middle Maestrichtian (Fig. 2). According to Parrish and Spicer (1988), in north Alaska the climate was slightly drier in the Campanian–Maestrichtian than in the Late Albian and Cenomanian.

Seasonal precipitation in this territory cannot be discussed because of the lack of available data. But as far as I know, no sedimentological evidence of periodic occurrences of arid conditions (desiccation fissures, and others) has been recorded.

(4) *Light regime.* The arctic light regime has a specific character due to the high latitude position of the area. The specific features include the following: (a) quantity of solar energy, (b) daily and annual photoperiodicity, and (c) qualitative light composition.

High latitudes annually receive about half the solar energy of near-equatorial areas (Fig. 4). In winter, the photosynthesis may occur, if at all, at high latitudes during a small portion of the day, but in summer, the daylight duration at high latitudes considerably exceeds that at low latitudes (Fig. 5a). The annual amount of solar energy at high latitudes is much less than that at low latitudes: in winter the near-polar areas are charac-

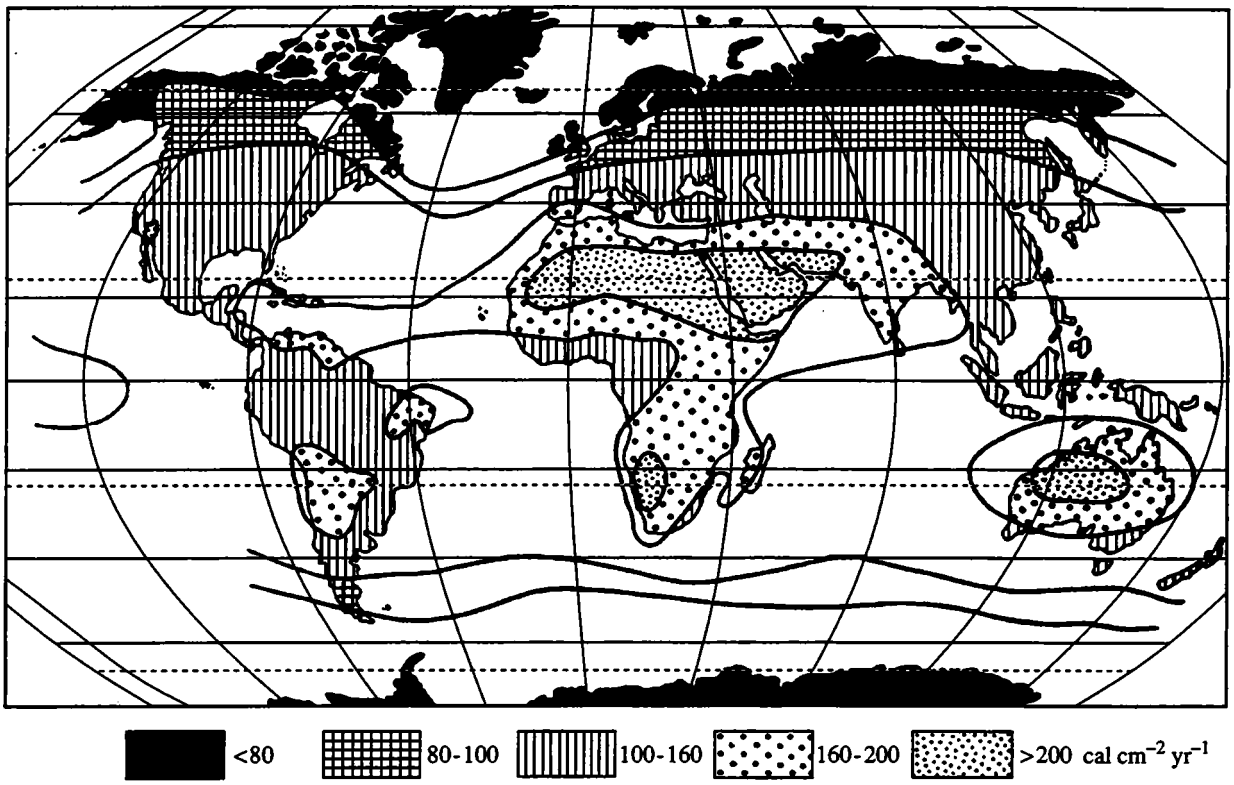


Fig. 4. Annual solar radiation (300 - 2200 nm) on the Earth's surface (after Larcher, 1976).

terized by a distinct deficiency in daylight, while in semiannual summer the quantity of solar radiation at high latitudes is nearly equal to that at low latitudes due to the longer solar day (Figs. 5a and 5b).

In addition, the reduced solar energy that the polar plants received at high latitudes was compensated by its photosynthetically beneficial qualitative composition (Figs. 5c - 5e): the high latitude solar energy contains more diffuse light, which is better utilized by plants than the direct light and is absorbed almost completely (Shennikov, 1950). Prevalent diffuse solar light at high latitudes can be attributed to the relatively low position of the sun above the horizon, high vapor content in the atmosphere of the near-polar areas, and frequent cloudiness and fogs. The intensive volcanic activity, which manifested itself mostly in the Okhotsk–Chukotka volcanogenic belt, also occurred at the end of the Early and Late Cretaceous; water vapors, gases, and dust particles were erupted into the atmosphere and probably increased the solar light diffusion.

At high latitudes (75 - 85°N), the summer light regime presently passes into the winter one rapidly, within the span of a few weeks. The specimens of the Late Albian–Cenomanian relatively narrow late wood fossils, which were studied by Spicer and others (Spicer *et al.*, 1992) from northern Alaska, also indicate a rapid change in the high latitude daylight duration comparable with the one observed presently. The ratio between late and early woods is higher in the Campanian–Maestrichtian of north Alaska due to summer temperatures at the end of the Late Cretaceous that are cooler than at its beginning (Spicer *et al.*, 1992).

DISCUSSION

Upon examination of the available data concerning the Cretaceous broad-leaved deciduous floras of the near-polar areas of Asia and North America, the following phenomena call for explanation: (a) the occurrence of these floras at such high latitudes, (b) the dynamics of diversity and abundance of broad-leaved platanoid plants in these floras, as exemplified by the Cretaceous flora of the Anadyr'–Koryak Subregion, and (c) the morphological features of these plants: large-sized leaves with a great range of leaf size.

The absence of a sufficiently long cold winter period and a probable restriction of deciduous tree plant growth due to temperatures imply that the deciduousness of the polar forests (except for some conifers and, possibly, cycadophytes) can be attributed to the deficiency in winter light rather than to low temperatures. The above-mentioned finds of Cenomanian wood fossils with distinct annual rings in Chukotka also indicates the seasonal nature of plant growth that is controlled by scarce winter light. On the other hand, during the summer growth season, long solar days and an increased content of diffuse light in the total luminous flux at high latitudes, as well as adequate amounts of heat and humidity, provided the plants of these forests with a sufficient amount of solar energy for active

photosynthesis, which is comparable with that received by the mid- and low-latitude plants. Thus, contrary to the commonly held opinion, the recent forest distribution in the Arctic is restricted by the deficiency of heat rather than scarcity of light. According to experimental observations, the modern plants can survive a 10-week period of artificial "dark polar winter" with light deficiency. Moreover, the plants growing at 4°C showed better results than those growing at 15°C (Read and Francis, 1992).

These climatic conditions seem to favor intensive coal accumulation throughout the high latitudes of the northern hemisphere. Sal'nikov *et al.* (1990) recognized several epochs of coal formation in the Late Cretaceous of the northwestern Pacific area. These are confined to the Late Albian–Cenomanian, Late Turonian–Santonian, Early Campanian, and Late Maestrichtian. In northern Alaska, coal accumulated mostly in the Late Albian–Cenomanian and to a lesser extent in the Late Campanian–Maestrichtian. A minor coal formation was also recorded in the Coniacian (Spicer *et al.*, 1992). The Cretaceous coal-bearing deposits are also known from northern Siberia (Gol'bert, 1987). Coal can be formed when accumulation of the organic material exceeds its decay. In the Late Cretaceous of the near-polar areas of Asia and North America, coal formation was ensured by high plant productivity in the summer due to high temperature, sufficient humidity, and a favorable light regime, and by the low rate of the organic matter decay in the winter due to the relatively low temperature. The fossil leaves from the Upper Cretaceous of Alaska show no signs of decomposition after falling at the end of the growth season. According to Spicer (Spicer *et al.*, 1992), this indicates a fall in winter temperatures below 4°C, which causes a decrease in microbial activity.

The solar light regime is probably responsible for widespread Cretaceous broad-leaved angiosperms at high latitudes. Diffuse solar light has no infrared rays, which are for the most part not absorbed by chlorophyll (Larcher, 1976) but may cause an overheating of large leaves. The leaf size of numerous modern species of the northern hemisphere is bigger in individual plants existing farther northward. According to Warming (1902), this may be due to the longer lasting effect of comparatively weak light. Intensive direct solar light inhibits shoot and leaf growth. Leaves of the lower canopy are known to be broader and larger than those exposed to full light (Larcher, 1976). So, the leaves of *Majantemum bifolium* (L.) F. Schmidt that were grown in the sunlight are about one third smaller than those from shaded areas (Warming, 1902).

The modern largest-leaved plants grow below the canopy in the tropical rain forests (Vasil'ev *et al.*, 1978), where the weak diffuse light dominates while direct rays only slightly penetrate. The highest intensity of photosynthesis of the broad-leaved trees is attained when the relative illumination is 30% or less of the maximum value (Spurr and Barnes, 1980). Experimental data shows that the seedlings of *Platanus occidentalis* L. grow most rapidly when the illumination is about 20% of the maximum one (Spurr and Barnes, 1980).

Leaf size depends on humidity as well as on light quantity and quality: large leaves only evolve in very humid air, which hampers leaf transpirations, and with a large water supply providing quick leaf growth.

Based on experimental data and mathematical models for the physiological processes in a leaf, Parkhurst attempted to define the conditions and leaf sizes that are most beneficial photosynthetically per unit of water loss (Wintsch, 1979). According to his model for "water-utilization effectiveness" (Fig. 6), larger leaves generally have an advantage over the smaller ones under conditions of high temperature and low illumination; large leaves are capable of remaining cooler and losing less water through evaporation than the smaller ones. In particular, this model explains why leaves of the lower canopy are bigger than those exposed to full light and why plants with small leaves are most typical of the cold climate regions and of the areas with intensive solar radiation (steppes, deserts).

It may thus be inferred that the Cretaceous broad-leaved deciduous forests were widespread in the near-polar regions of the northern hemisphere owing to the humid warm-temperate high-latitude climate of the area. This climate was characterized by specific light conditions: scarce light in winter and long daylight duration with comparatively weak and predominantly diffuse light throughout the summer growth period.

The broad-leaved platanoid plants of the near-polar areas of the northern hemisphere were most abundant and diverse in the Turonian to Coniacian and at the end of the Cretaceous, as indicated by the development of these plants during the Cretaceous in the Anadyr'–Koryak Subregion. In the Late Albian to Cenomanian broad-leaved platanoid plants were common but not very diverse components of some Arctic floras and were rare or absent in others. In the Santonian to Campanian, the abundance and diversity of these plants were considerably reduced throughout this territory. This development pattern of the platanoid plants may be related to certain climatic changes: there were repeated climatic warmings and dryings in the Cenomanian and Santonian to Campanian of northern Siberia and northeastern Russia (Fig. 2). The aridization itself must have had an unfavorable effect on the development of broad-leaved plants. In addition, this was accompanied by reduced cloudiness and water vapor content in the atmosphere of the near-polar areas. This resulted in a greater amount of direct solar radiation in the total luminous flux and in reduced broad-leaved forests.

The great variability in leaf size of individual species typical of the majority of the Late Cretaceous Arctic broad-leaved angiosperms can be explained to some extent by the leaf position within the tree crown (Wolfe, 1987): larger leaves grew on the shaded parts of plants below the canopy, whereas smaller ones developed in the upper, well-illuminated parts. This variability may

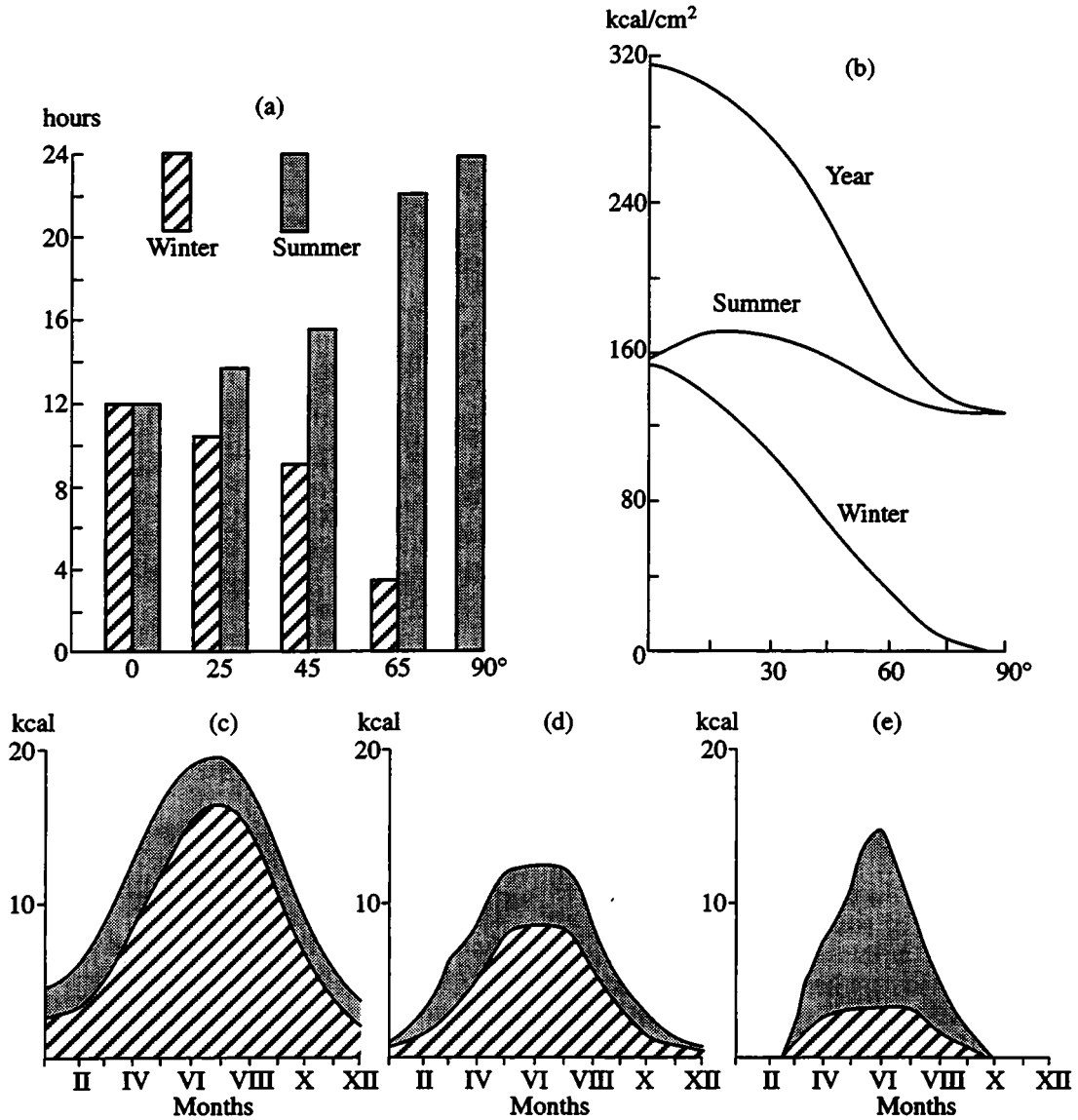


Fig. 5. Solar radiation at different latitudes.

(a) – solar day length in the shortest winter day and in the longest summer day (Khromov, 1968); (b) – incoming solar radiation on the horizontal surface during the winter and summer semiannual periods and the whole year (disregarding the atmosphere absorbtion and diffusion) (Khromov, 1968); (c) - (e) – yearly quantitative variations of direct (dashed area) and diffuse (dotted area) solar radiation near the equator (c), at middle (d) and high (e) latitudes (Shennikov, 1950).

also be related to the seasonal character of annual shoot development.

I suggested a reconstruction of the annual shoot of *Paraprotophyllum ignatianum* (Krysht. et Baik.) Herman (Herman, 1990). Taking into account the modern hornbeam *Carpinus betulus* L., which shows a similar correlation of length, relative width of leaves, and leaf symmetry as a model for this reconstruction, it may be suggested that early spring leaves on the shoot of the fossil plant were short, broad, and frequently asymmetric, whereas later spring and summer leaves were longer, with a reduced width and increased symmetry. Leaves of the last nodes of the annual shoot were presumably smaller and symmetric. This reconstruction agrees well with Parkhurst's model (Fig. 6): in contrast to the large leaves in the middle of the annual shoot, which grew at high spring-summer temperatures, the smaller, early spring and summer-autumn leaves probably grew at lower temperatures.

A NEW SPECIES OF *PLATANUS* OF THE LATE ALBIAN–CENOMANIAN OF CHUKOTKA

This species is derived from the middle Krivaya Rechka Subformation exposed on the right bank of the Grebenka River (the right tributary of the Anadyr' River middle reaches), 4 km downstream of the mouth of the Malaya Grebenka River (Shchepetov *et al.*, 1992). These deposits are represented by interbedding

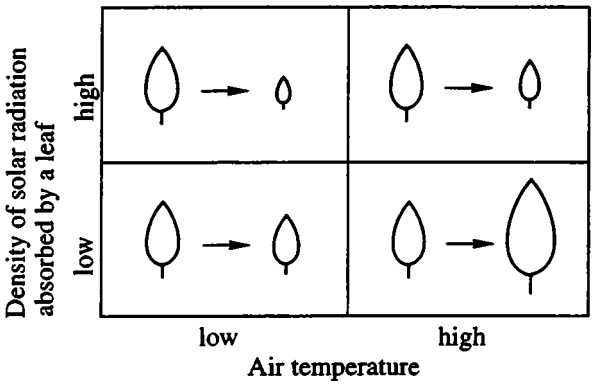


Fig. 6. Expected trends in natural selection of leaf size dependent on light conditions and air temperature, as predicted by Parkhurst's model (Wintsch, 1979).

conglomerates, gritstones, sandstones, and siltstones; the lithological composition of the beds along the strike varies. Almost all fine- and medium-grained rock varieties contain plant detritus or plant imprints. The total thickness of the middle Krivaya Rechka Subformation in the section on the right bank of the Grebenka River is 105 - 115 m. These deposits and the enclosed fossil plants are referred to as Late Albian–Early Cenomanian on the basis of their stratigraphic position (below the Gornaya River sequence containing the Early Cenomanian remains of ammonites and bivalves) and spore-pollen records (Shchepetov *et al.*, 1992).

Fossil leaves of the new species were in general collected from a member of greenish-grey, compact fine-grained sandstones, 1 m thick, from the upper part of the subformation in the southern part of the exposure (Locality 35: Shchepetov *et al.*, 1992). The most abundant leaf imprints of *Platanus louravetlanica* sp. nov. forming "the leaf accumulation" were found together with remains of *Sagenopteris variabilis* (Velen.) Velen., *Nilssonia serotina* Heer, *Nilssonia* sp., *Nilssoniocladus* sp., *Ginkgo* ex gr. *adiantoides* (Unger) Heer, *Sphenobaiera vera* Samyl. et Shczep., *Phoenicopsis* ex gr. *angustifolia* Heer, *Pseudotorellia* (?) sp., *Taxites* ex gr. *intermedius* (Hollick) Samyl., *Pityospermum semiovale* Samyl., *Sequoia* sp. (a cone), *Magnoliaephyllum alternans* (Heer) Seward, *Menispermites* ex gr. *septentrionalis* Hollick, *Scheffleraephyllum* (= *Debeya* ?) *venustum* (Philipp.) Philipp., *Cissites* sp., *Dalembia vachrameevii* Lebed. et Herman, *Grebenkia anadyrensis* (Krysht.) E. Lebed., and *Dicotylophyllum* sp. cf. *Palaeonuphar nordenskioldii* (Heer) Bell. Less abundant and poorly preserved imprints of *Platanus louravetlanica* sp. nov. also occur in flora-bearing deposits of this exposure other than Locality 35 (Shchepetov *et al.*, 1992).

The studied specimens are stored in the Northeastern Complex Research Institute, Far East Division, Russian Academy of Sciences (NECRI FED RAS), Magadan, collection PF-1. S.V. Shchepetov (NECRI FED RAS) and I described the new species.

GENUS *PLATANUS* LINNAEUS

Platanus louravetlanica Herman et Shczepetov, sp. nov.

Plate

Platanus aff. *embicola:* Shchepetov, Herman, and Belaya, 1992. Plate 41, Fig. 3; Plate 42, Fig. 2; Plate 43, Fig. 2; Plate 44, Fig. 6; Plate 45, Figs. 1 - 3; Plate 46, Figs. 1 - 3; Plate 47, Figs. 1 - 3; Plate 48, Figs. 1 - 3.

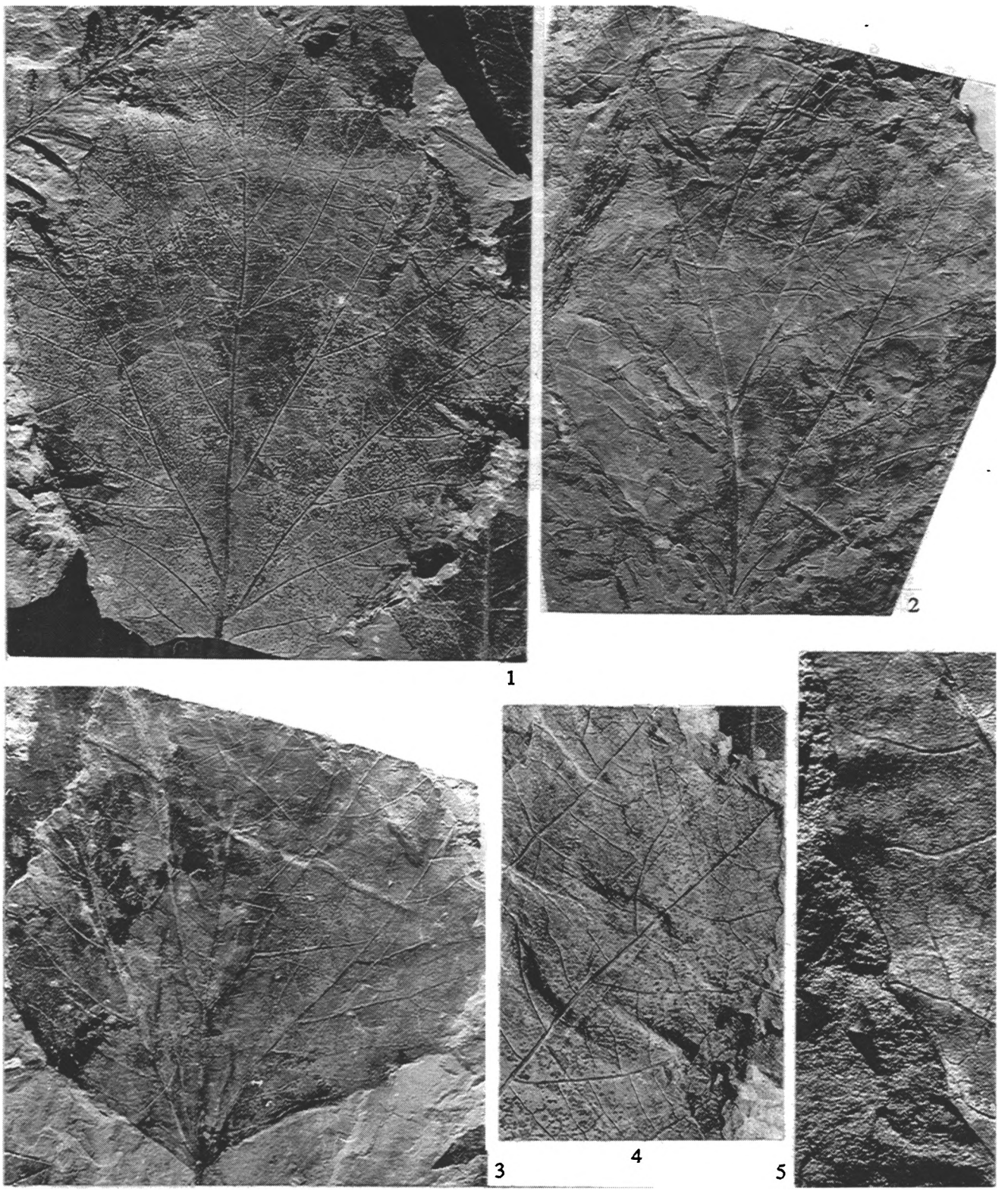
Name derivation – from "louravetlan" (Chukotsk) – "chukcha" (Leont'ev and Novikova, 1989).

Holotype – NECRI FED RAS, collection PF-1, no. 1007/35-632a, the middle reachers of the Grebenka River (the Anadyr' River basin); the middle Krivaya Rechka Subformation, Upper Albian–Lower Cenomanian.

Description (Fig. 7). Simple asymmetrical leaves of medium and large size, 7 to 16 cm in length and 6 to 14 cm in width, with small lateral lobes. The leaf shape is rounded, oval, broadly rhomboid, broadly, or rounded-obovoid. Broad or narrow wedge-shaped, decurrent leaf base. Apices of both a leaf and a pair of lateral lobes are attenuated or blunted. Small-sized, triangular lateral lobes. The pomeria are relatively narrow; their width is 1.2 - 1.5 times larger than the distance between the basal vein and the lower suprabasal one. The left and right lobes of variable size are frequently located at different height (Figs. 7a and 7c). The leaf margin is denticulate. The teeth are acute, triangular, with small glands on the apices. The teeth both of different specimens and of a single leaf may vary in size (Fig. 7; Plate, Figs. 4 and 5). Sinuses between the teeth are rounded. A petiole is long, 6 - 7 cm and longer (incompletely preserved).

Leaves have a palmately-pennate craspedodromous venation. Basal veins spread out from the midvein asymmetrically. In some specimens they are opposite, 5 - 25 mm above the leaf base, well developed or comparable in thickness and degree of branching with secondary veins lying above and below, straight or nearly straight. One specimen may show veins of different thickness and length. One to two unramified acroscopic branches and five to seven basiscopic branches, the largest of which produce one to three pairs of branches, depart from each basal vein. There are up to four pairs of infrabasal veins, which can be either thin or short, unramified or well-developed, and have two to three pairs of branches. Secondary suprabasal veins occur in pairs of 4 to 5; the lower pairs have some branches and the upper ones have none. Tertiary venation varies from orthogonally-reticulate to branched-scalariform. Sometimes the third and fourth order veins are difficult to distinguish from each other. The fourth order venation is orthogonally-reticulate or similar to that (Fig. 7f).

Comparison. The new species differs from the other species of *Platanus* in asymmetrical patterns of the leaf base and a leaf lamina in general (among them symmetry in arrangement and the size of the lateral lobes), in commonly asymmetrical departure and variable thickness of lateral basal veins, as well as in the transitional



Platanus louravetlanica sp. nov.

1 – holotype, specimen no. 1007/35-632a (×1); 2 – specimen no. 1007/35-649 (×1); 3 – specimen no. 1007/35-629a (×2/3); 4 – lateral lobe, holotype specimen no. 1007/35-632a (×2); 5 – marginal teeth, specimen no. 1007/35-649 (×4).

character of tertiary venation from orthogonally-reticulate to branched-scalariform. Most recent and fossil forms of *Platanus* have scalariform and branched-scalariform tertiary venation. *Platanus louravetlanica* is distinguished from the closest species *P. newberryana* Heer by these features (Capellini and Heer, 1867; Herman and Lebedev, 1991). The new species differs from another close species, *P. embicola* Vakhrameev from the Cenomanian of western Kazakhstan (Vakhrameev, 1952), as a rule in its narrower leaves and less developed acroscopic branches of basal and lower suprabasal secondary veins. Unlike *P. louravetlanica, P. williamsii* Bell (Bell, 1963) from the Cenomanian of western Canada, it also has broader leaves and more developed basal veins, which go upward more steeply, similar to the secondary suprabasal ones.

The present species differs from *P. credneriifolia* Budantsev from the Turonian–Coniacian of Kamchatka (Budantsev, 1983) in its symmetrical leaf structure, numerous secondary overbasal veins, and less advanced tertiary venation.

P. latibasalis Hollick and *P. valida* Hollick from the Cenomanian of the Yukon River basin in Alaska (Hollick, 1930), known only in fragments, seem similar to the new species, but the first species has a truncate leaf base and stronger basal veins and the second one has broader leaf lamina, broader pomeria, stronger basal veins, and more regulated scalariform tertiary venation.

Comments. The leaf imprint described by Krishtofovich (1958) from the same locality as *Credneria inordinata* Hollick may belong to *P. louravetlanica*. But as it is incomplete, this imprint cannot be confidently identified.

Distribution: Upper Albian–Lower Cenomanian of the Anadyr' River basin, northeastern Russia.

Material: more than 20 variably preserved leaf imprints from the middle Krivaya Rechka Subformation in the middle reaches of the Grebenka River (the Anadyr' River tributary).

CONCLUSION

(1) In the Anadyr'–Koryak Subregion the Late Cretaceous broad-leaved platanoid plants are represented by 17 species of the *Platanus, Arthollia, Paraprotophyllum*, and *Pseudoprotophyllum* genera. These appeared in the Late Albian–Cenomanian (one species of *Platanus*) and became most diverse and abundant in the Turonian (three species of *Platanus*, two species of *Arthollia*, and two species of *Paraprotophyllum*) and Coniacian (three species of *Platanus*, two species of *Arthollia*, two species of *Paraprotophyllum*, and one species of *Pseudoprotophyllum*). Their diversity and abundance decreased considerably in the Santonian–Middle Maestrichtian (three species of *Platanus* and one species of *Paraprotophyllum*) and increased again,

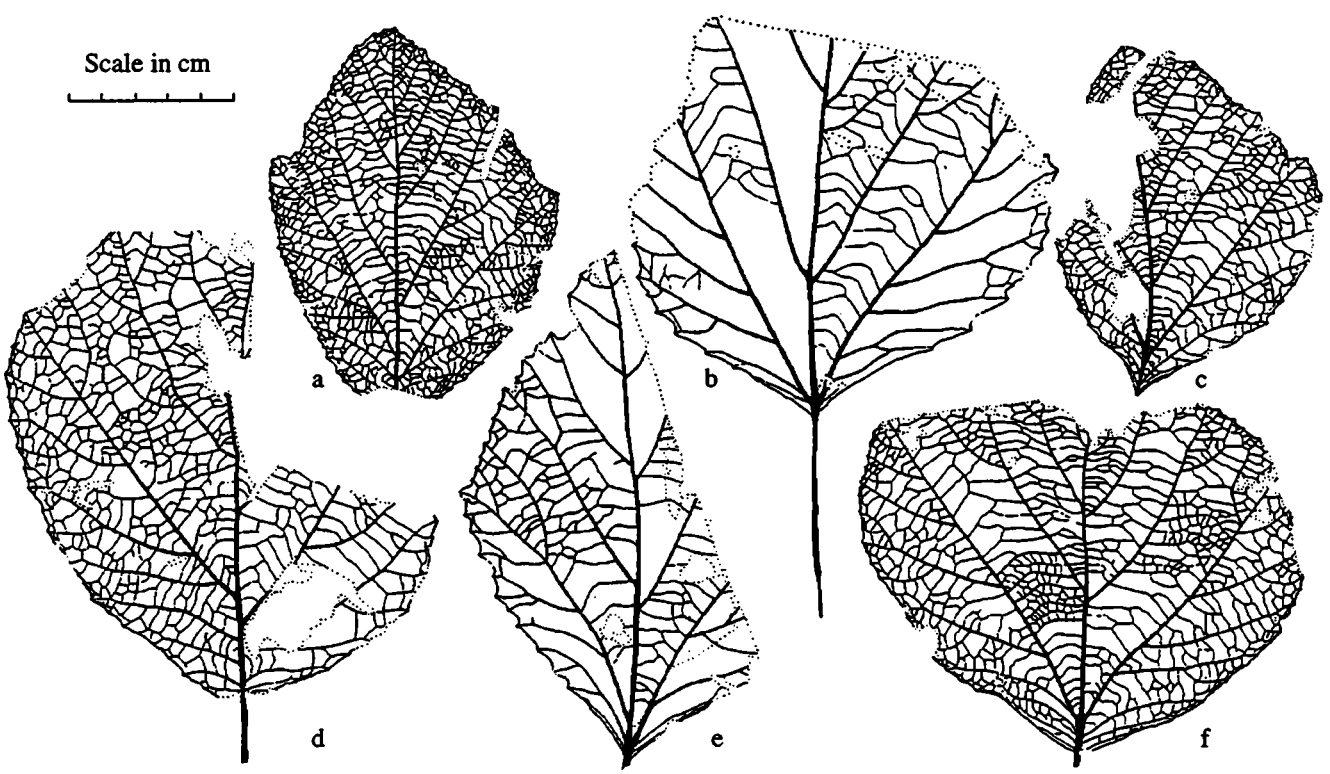


Fig. 7. *Platanus louravetlanica* sp. nov.

a – holotype, specimen no. 1007/35-632a; b – specimen no. 1007/35-629a; c – specimen no. 1007/35-649; d – specimen no. 1007/35-653; e – specimen no. 1007/35-651a, b; f – specimen no. 1007/35-646b.

though not so extensively, at the end of the Maestrichtian (one species of *Platanus*, *Arthollia*, and *Pseudoprotophyllum* genera).

(2) The wide distribution of the Late Cretaceous broad-leaved deciduous angiosperms, primarily the platanoid plants, throughout the near-polar areas of Asia and North America can be attributed to the warm and humid climate and the high-latitude light regime, which is characterized by the long duration of daylight and the weak and mainly diffuse solar light during the summer growth season. The deciduous nature of these plants is related to the scarcity of light rather than to the heat deficiency during the winter period.

(3) The above-described high-latitude light regime is responsible for the specific morphology of the Cretaceous near-polar angiosperms: the large absolute size of leaf laminas and the great range of leaf size of an individual species. The first feature is presumably related to the predominant diffuse light during the growth season and the second one, with the seasonal character of annual shoot development and the leaf position in the tree crown.

(4) Relative warmings and aridization in the Cenomanian and Santonian–Campanian unfavorably affected the abundance and diversity of the large-leaved platanoid plants in the near-polar areas of Asia and North America.

(5) A new species *Platanus louravetlanica* Herman et Shchepetov from the Upper Albian–Lower Cenomanian of the Anadyr' River basin, northeastern Russia, is described.

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Evolution of the biosphere

Paleogene Radiolarians of the Troodos Massif (Cyprus)

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Abstract – Radiolarians were studied in 67 samples collected from a continuous section of the Paleogene deposits located near the village of Perapedhi, Cyprus. Two units of Kozlova's (1990) temperate Boreal scale, the *Buryella tetradica* and *Petalospyris foveolata* zones, are distinguished in the Paleocene deposits. Standard zones of tropical radiolarian scale are defined in the Eocene part of the section. The analyzed taxonomic composition shows that radiolarian assemblages from the Paleocene and basal Lower Eocene intervals of the Perapedhi section are very similar to the coeval radiolarian fauna from provinces of the Volga River, Ciscaucasia, and other regions. This is a consequence of the sublatitudinal geographic position of corresponding sea basins and climatic changes during the Paleocene and Early–Middle Eocene.

INTRODUCTION

The Perapedhi section, located on the southern slope of the Troodos ophiolite massif, is unique in certain aspects. It represents a continuous sequence of the Uppermost Cretaceous–Paleogene deposits. The base of the sequence consists of the Perapedhi Formation resting on ophiolites and is overlain by bentonitic clays and claystones of the Kannaviou Formation, which bears the Campanian–Maestrichtian radiolarians. Above the Kannaviou Formation, the section of carbonate Upper Cretaceous–Cenozoic sediments is subdivided into the Lower, Middle, and Upper Lefkara formations.

The Cenozoic deposits of Cyprus have been well described and comprise a series of lithostratigraphic formations (Henson *et al.*, 1949; and others). However, only planktonic foraminifers have been studied among their faunal groups, but relevant zonation units were distinguished only in the Paphos area.

First data on radiolarians from the Paleogene deposits of Cyprus was published by Mantis (1977), who reported on an assemblage of 28 species recovered from massive marls and limestones of the Upper Lefkara Formation in association with foraminifers of the *Hantkenina alabamensis* Zone, which were identified as Late Eocene forms.

In fact, the *Hantkenina alabamensis* Zone of the Crimea–Caucasus foraminiferal scale corresponds to the Middle Eocene *Orbulinoides beckmanii* Zone of the standard scale. Radiolarians described in this article suggest the same age.

The first samples for this study were collected from several complementary sections in 1987 as I was studying the lithology and stratigraphy of Cyprus. At that time, I discovered radiolarians in the Upper Cretaceous–Oligocene deposits near the village of Perapedhi. Later in 1990, V.A. Krasheninnikov sampled the same section in detail and submitted additional materials to my collection. I sincerely appreciate his kind contribution.

The 67 studied rock samples contain radiolarian assemblages that vary in diversity and preservation. L.G. Bragina assisted the determination of Cretaceous radiolarians and V.A. Krasheninnikov studied the foraminifers from that group of samples.

The Cretaceous and Eocene rocks were subdivided according to the standard tropical zonation by radiolarians (Foreman, 1977; Sanfilippo *et al.*, 1985), and sediments of the Paleocene interval according to Kozlova's (1984, 1990) zonation for temperate Boreal provinces (Figs. 1, 2). Below, I consider data on detected radiolarian fauna and stratigraphic units of the Upper Cretaceous–Eocene deposits of the Perapedhi section using local subdivisions – formations and members.

The lithologic units usually recognized among the Upper Cretaceous–Paleogene rocks of the Perapedhi locality are the Kannaviou (bentonitic clays), Lower Lefkara (soft marls silicified in the middle part), Middle Lefkara (intensively silicified limestones), and Upper Lefkara (thick-bedded chalky marls) formations (Fig. 2).

PERAPEDHI SECTION STRATIGRAPHY ACCORDING TO RADIOLARIANS

Kannaviou Formation

Cretaceous. Lower-Middle Campanian. Light brown bentonitic clays contain a diverse assemblage of well-preserved radiolarians. Their specific composition is characteristic of the *Amphipyndax pseudoconulus* Zone. Specimens of the *Dictyomitra, Stichomitra,* and *Pseudoaulophacus* genera are dominant and include *Dictyomitra duodecimcostata, D. torquata, D. densicostata, D. kozlovae, D. formosa, Stichomitra cechena, S.* aff. *campi, S. alamedaensis, Pseudoaulophacus floresensis,* and *P. praefloresensis.*

The above forms are abundant, but the index species have not been detected. The assemblage also contains many spongodiscids. Its most characteristic elements are *Amphipyndax stocki, Alievium gallowayi, Rhopalastrum tumidum, Septinastrum dogieli, Cyrtocaspa,* sp., and *Praeconocaryomma universa.*

The thickness is 3 m.

Lower Lefkara Formation

Upper Campanian–Maestrichtian. Straticulate marls overlie bentonitic clays and comprise separate interbeds of light clayey limestones. The marls contain the radiolarian assemblage of the *Amphipyndax tylotus* Zone, including the index species and *Xitus asymbatos, Hemicryptocaspa* sp., *Cyrtocalpis operosa, Theocampe* sp., *Dictyomitra multicostata, D. formosa, D. kozlovae, Amphipyndax stocki,* and *Alievium gallowayi.*

The thickness is 5 m.

Lower Paleocene. Danian Stage. Grey and brownish marls of the Danian conformably rest on the Maestrichtian marls and contain abundant, but poorly or moderately preserved radiolarians. It is difficult to determine them because data indicating this stratigraphic interval is limited. The *Lithocampe* sp., *Artostrobus* sp., and *Cornutella* sp. forms occur in the lower part of the unit, where sphaerids and spongodiscids are dominant. Several representatives of the *Amphipyndax* and *Dictyomitra* genera were also encountered here, though they are more characteristic of the Upper Cretaceous deposits. In the middle part, radiolarians are more diverse and better preserved. Forms commonly occurring here include *Cornutella californica, Actinommura* aff. *californica, Lithocampe* aff. *marinae, Stylosphaera coronata coronata, S. goruna, Lithelius* sp., *Spongodiscus americanus,* and many smaller spyrids. First representatives of the characteristic Paleocene genus *Buryella* (*B. alifera* Kozlova) appear at the same level. In the upper part of the unit, the assemblage is considerably poorer, though common specimens of the *Buryella* genus (*B. alifera* and *B. pentadica*), numerous species of *Stylosphaera coronata coronata,* and rare forms of *Petalospyris* sp. and *Theocotyle auctor* are still present.

In the Lower Paleocene (Danian?) of the Middle Volga province (Lower Syzran' Beds) Kozlova identified the *Buryella alifera* Zone, an assemblage lacking analogues of tropical provinces. Despite the available index species, I failed to distinguish this zone of the Danian in the Perapedhi section, because many associated forms are lacking. These deposits are distinguished as beds with *Buriella alifera.*

The total thickness of the Danian sediments is 300 m.

Upper Paleocene. This interval includes marls with chert lenses and impoverished, moderately preserved radiolarians. The assemblage is barren of index species and characteristic forms of oceanic Paleocene fauna; thus, the standard tropical zonation cannot be applied (Sanfilippo *et al.*, 1985).

However, the *Buryella tetradica* Beds and *Petalospyris foveolata* Zone of temperate Boreal scale, which was suggested by Kozlova (1984) to the Paleogene of the Volga provinces, have been identified. The inferred Paleocene age of the member is confirmed by rare planktonic foraminifers of the *Morozovella conica truncata* Zone in its lower part, and of the *Morozovella velascoensis* Zone discovered higher.

The total thickness is about 400 - 500 m.

The *Buryella tetradica* Beds contain abundant index species associated with *Cenosphaera* aff. *subbotinae, Thyrsocyrtis* sp., *Becoma* sp., *Lithelius foremanae, Theocotyle auctor, Phormocyrtis striata exquisita, Thecosphaerella rotunda, Spongodiscus americanus, Tripodiscus* aff. *trilobatus,* and other forms.

Species of *B. tetradica* are most abundant at the lower boundary of the unit. Its upper boundary coincides with the base of the *Petalospyris foveolata* Zone. Tropical forms characterizing this interval are absent, and available species of a wide geographic distribution occurring in temperate boreal provinces correlate solely to Kozlova's (1984) zonation scheme.

The main characteristic species of the *Petalospyris foveolata* Zone are *Buryella tetradica, Petalospyris foveolata, Lychnocanoma auxilla,* and *Phormocyrtis striata exquisita.* Associated forms are *Gorgospyris incerticoronata, Tripodiscinus* aff. *trilobatus, Stylosphaera coronata coronata, Spongotrochus* sp., *Artostrobus* sp., and some others. Specimens of *Petalospyris foveolata, Lychnocanoma auxilla,* and *Gorgospyris incerticoronata* mark the unit base.

The top is distinguished by a decreasing abundance of small spyrids and by the disappearance of *Tripodiscinus* aff. *trilobatus* and *Petalospyris foveolata.*

The thickness is about 100 m.

Lower Eocene. The Paleocene–Lower Eocene boundary is placed at the top of the foraminiferal *Morozovella velascoensis* Zone (Bolli, 1957, 1966; Blow, 1969; Krasheninnikov 1978; Toumarkine and Luterbacher, 1985), and corresponds to the median level of the radiolarian *Bekoma bidartensis* Zone. Yet radiolarians discovered from the Perapedhi section are too vague to identify this zone here. At the same time, the *Buryella tetradica* and *Petalospyris foveolata* zones of Kozlova's scheme have no accurate age determinations.

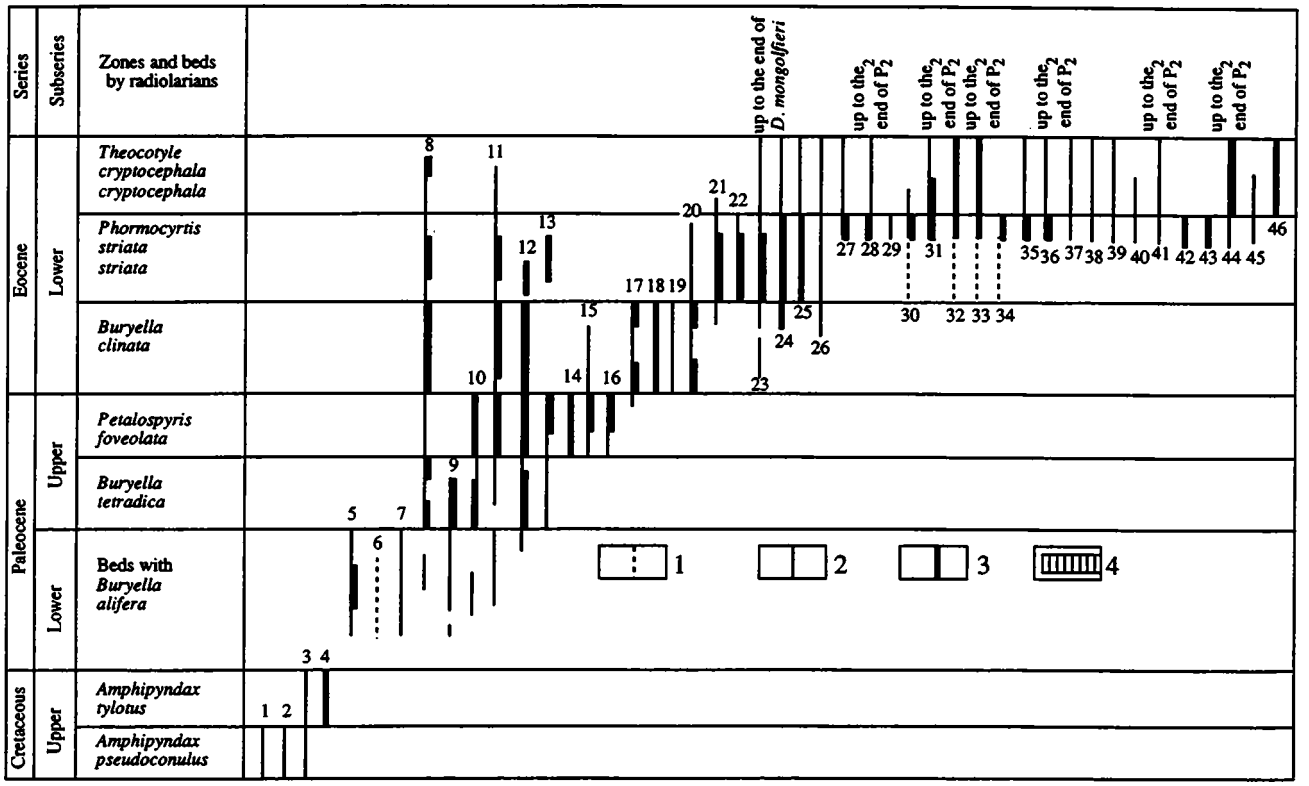

Fig. 1. Stratigraphic distribution of the most characteristic radiolarian species in the Perapedhi section.

Radiolarian species: 1 – *Praeconocaryomma universa*, 2 – *Dictyomitra torquata*, 3 – *D. kozlovae*, 4 – *Amphipyndax tylotus*, 5 – *Lithocampe* aff. *marinae*, 6 – *Buryella alifera*, 7 – *Stylosphaera goruna*, 8 – *Spongodiscus americanus*, 9 – *Theocotyle auctor*, 10 – *Actinommura* aff. *californica*, 11 – *Phormocyrtis striata exqusita*, 12 – *Buryella tetradica*, 13 – *Entapium regulare*, 14 – *Petalospyris foveolata*, 15 – *Lychnocanoma auxilla*, 16 – *Gorgospyris incerticoronata*, 17 – *Buryella clinata*, 18 – *Thyrsocyrtis hirsuta hirsuta*, 19 – *Dendrospyris mitra*, 20 – *Phormocyrtis turgida*, 21 – *Eusyringium lagena*, 22 – *Lithochytris archaea*, 23 – *Petalospyris fiscella*, 24 – *Lychnocanoma ponderosa*, 25 – *Phormocyrtis striata striata*, 26 – *Spongotrochus paciferus*, 27 – *Calocycloma castum*, 28 – *Lychnocanoma bellum*, 29 – *Cromyodruppa regularia*, 30 – *Pterocodon ampla*, 31 – *Stylotrochus harlestonensis*, 32 – *Lamptonium colymbus*, 33 – *Podocyrtis papalis*, 34 – *Lamptonium fabaeformae*, 35 – *Calocycloma ampulla*, 36 – *Petalospyris tumidula*, 37 – *Axoprunum visendum*, 38 – *Lithomespilus mendosa*, 39 – *Amphicraspedum prolixum*, 40 – *Porodiscus parvus*, 41 – *Calocyclas hispida*, 42 – *Lychnocanoma anacolum*, 43 – *Giraffospyris lata*, 44 – *Calocyclas asperum*, 45 – *Lamptonium pennatum*, 46 – *Theocotyle cryptocephala cryptocephala*, 47 – *Lophoconus bicorne*, 48 – *Thecosphaera eocenica*, 49 – *Podocyrtis aphorma*, 50 – *Rhopalocanium ornatum*, 51 – *Dictyoprora mongolfieri*, 52 – *Spongotrochus radiatus*, 53 – *Podocyrtis diamesa*, 54 – *Theoconus anaclasta*, 55 – *Stylosphaera* aff. *irinae*, 56 – *Lithochytris vespertilio*, 57 – *Thyrsocyrtis rhizodon*, 58 – *Lithocyclia aristotelis*, 59 – *Theocotylissa ficus*, 60 – *Thecosphaera californica*, 61 – *Podocyrtis phyxis*, 62 – *Hexalonche senta*, 63 – *Thyrsocyrtis triacantha*, 64 – *Periphaena heliasteriscus*, 65 – *Lithocyclia ocellus*, 66 – *Podocyrtis ampla*, 67 – *Spongodiscus phrix*, 68 – *Podocyrtis fasciolata*, 69 – *Theocampe amphora*, 70 – *Eusyringium fistuligerum*, 71 – *Haliomma* aff. *melitomma*, 72 – *Podocyrtis mitra*, 73 – *Pterocodon tennelus*, 74 – *Theocorys* aff. *sporta*, 75 – *Theocotyle venesuelensis*, 76 – *Podocyrtis fasciata*, 77 – *Sethocyrtis laguncularis*, 78 – *Sethochytris triconiscus*, 79 – *Podocyrtis chalara*, 80 – *Pterocorythidium barbadense*, 81 – *Dictyoprora pirum*, 82 – *Carposphaera globosa*, 83 – *Cryptoprora ornata*, 84 – *Lychnocanoma tripodium*, 85 – *Lophocyrtis jacchia*, 86 – *Phormocyrtis embolum*, 87 – *Eucyrtidium montiparum*, 88 – *Theocampe* sp. 1, 89 – *Cycladophora erinacea*, 90 – *Lophophaena macrencephala*, 91 – *Lychnocanoma bandyca*, 92 – *Calocyclas semipolita*, 93 – *Theocorys* aff. *reticula*, 94 – *Calocyclas turris*, 95 – *Thyrsocyrtis bromia*, 96 – *Liriospyris clathrata*, and 97 – *Lithocampe* ex gr. *subligata*.

Occurrences of species: 1 – rare, 2 – common, 3 – abundant, and 4 – gap in sampling.

That is why in this study the Paleocene–Lower Eocene boundary was placed at the base of the higher *Buryella clinata* Zone.

Very hard, grey limestones with lenses and interbeds of brown silicified varieties yield moderately to well preserved radiolarians, allowing their subdivision according to the standard tropical scale, though the *Petalospyris fiscella* Zone of Kozlova (1990) can also be recognized in this member. Below, the discovered assemblages are characterized according to the tropical zonation scheme.

The *Buryella clinata* Zone contains well preserved and diverse radiolarians, among which *Buryella tetradica, Phormocyrtis striata exquisita, Lithomitra* ex gr. *lineata, Artostrobus* sp., *Thyrsocyrtis hirsuta hirsuta*, and *Lychnocanoma auxilla* are most abundant. They occur in association with *Buryella clinata, Dendrospyris mitra, Lychnocanoma ponderosa, Spongodiscus americanus, Phormocyrtis turgida, Ampicraspedum prolixum, Spongotrochus paciferus, Petalospyris fiscella*, and other forms. *Buryella clinata, Eucyrtidium* sp., *Dendrospyris mitra*, and *Thyrsocyrtis*

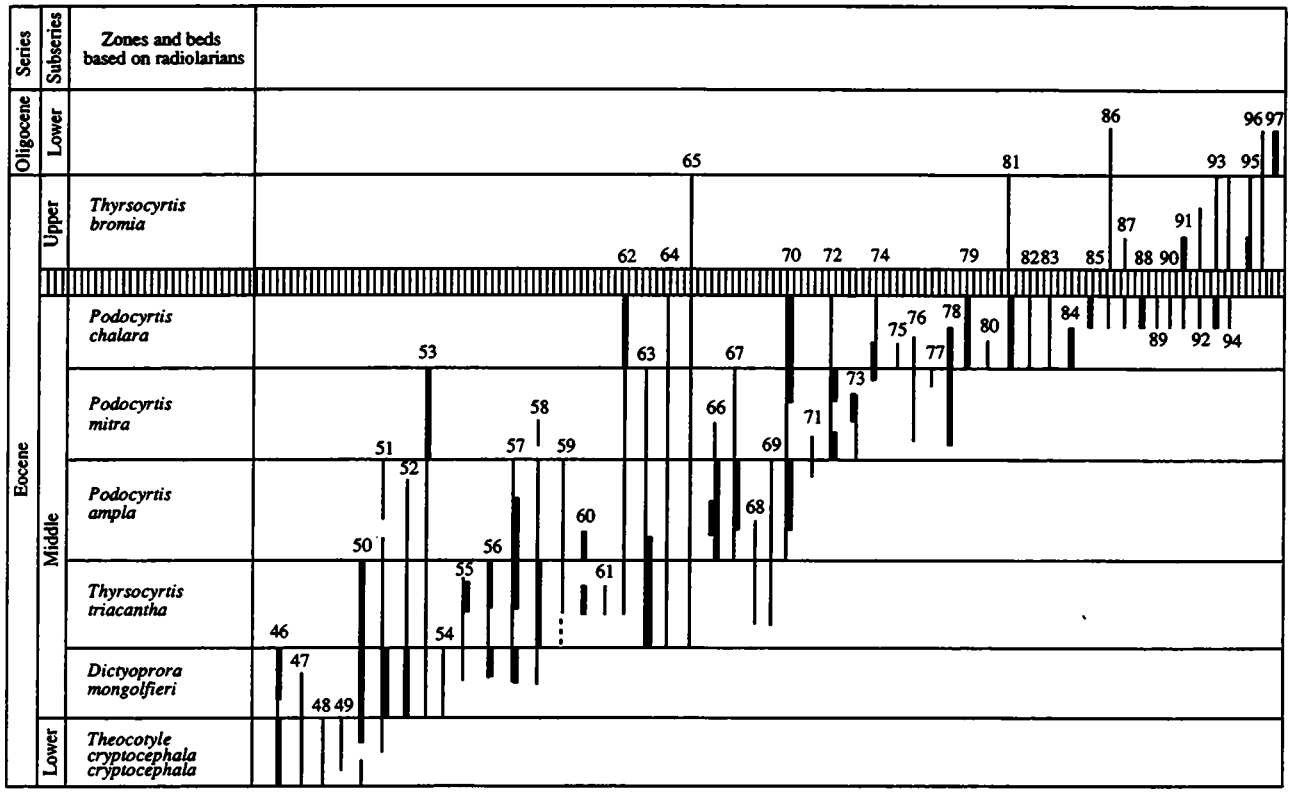

Fig. 1. (Contd.).

hirsuta hirsuta species appear at the base of the unit. Its top is marked by a decrease in the number of *Phormocyrtis striata exquisita* and *Buryella tetradica* forms, and by the disappearance of *Thyrsocyrtis hirsuta hirsuta* along with *Dendrospyris mitra*. The stratigraphic range of this zone in the Perapedhi section corresponds well to Kozlova's *Petalospyris fiscella* Zone.

The *Phormocyrtis striata striata* Zone is rich in well preserved radiolarians, including such highly abundant species as *Ph. striata striata, Phormocyrtis turgida, Theocotyle cryptocephala conica, Eusyringium lagena, Pterocodon ampla, Podocyrtis papalis, Petalospyris tumidula*, and *Lithocyrtis archaea*. Other forms also occurring here include *Cromyodruppa regularia, Lamptonium fabaeformae, Stylotrochus harlestonensis, Lithomespilus mendosa, Enthapium regulare*, and others. Species, appearing at the lower boundary of the zone and occurring extensively comprise *Phormocyrtis striata striata, Lithocyrtis archaea, Lamptonium fabaeformae fabaeformae, Pterocodon ampla, Lamptonium colymbus, Podocyrtis papalis, Petalospyris tumidula*, and *Clathrocyclas* aff. *unicum*. The *Eusyringium lagena* and *Petalospyris fiscella* forms also become more abundant here. Starting from this stratigraphic level, radiolarians show clearer features characteristic of normal "oceanic" assemblages, namely high specific diversity, the domination of nasselarian over subordinate spongodiscids, the absence of any species occurring in disproportionately high numbers relative to the others, and a mass abundance of various forms.

The *Theocotyle cryptocephala cryptocephala* Zone is also rich in diverse radiolarians. Its most characteristic species are *T. cryptocephala cryptocephala, Calocycloma ampulla, Thecosphaera eocenica*, and *Lophoconus bicorne*. Such forms as *Podocyrtis papalis, P. aphorma, Petalospyris tumidula, Rhopalocanium ornatum, Stylosphaera coronata laevis, Stylotrochus harlestonensis, Calocycloma castum, Enthapium regulare*, and *Calocyclas asperum* regularly occur along with species of wider stratigraphic and biogeographic ranges: *Stylosphaera coronata coronata, Phormocyrtis striata exquisita*, and *Lychnocanoma bellum*. Occasional specimens of *Dictyoprora mongolfieri* were detected in the upper part of the zone.

The lower zone boundary is marked by the appearance of the *Theocotyle cryptocephala cryptocephala, Lophoconus bicorne, Stylosphaera coronata laevis*, and *Thecosphaera eocenica* species; and the top of the zone is distinguished by the disappearance of *Podocyrtis aphorma* and *Thecosphaera eocenica* forms.

The thickness of the Lower Eocene deposits is about 200 m.

Middle Lefkara Formation

Middle Eocene. The Lower-Middle Eocene boundary is defined at the top of the *Globorotalia palmerae* or *Acarinina pentacamerata* zones of foraminiferal scale by Toumarkine and Luterbacher (1985) or between zones P9 and P10 (Blow, 1969).

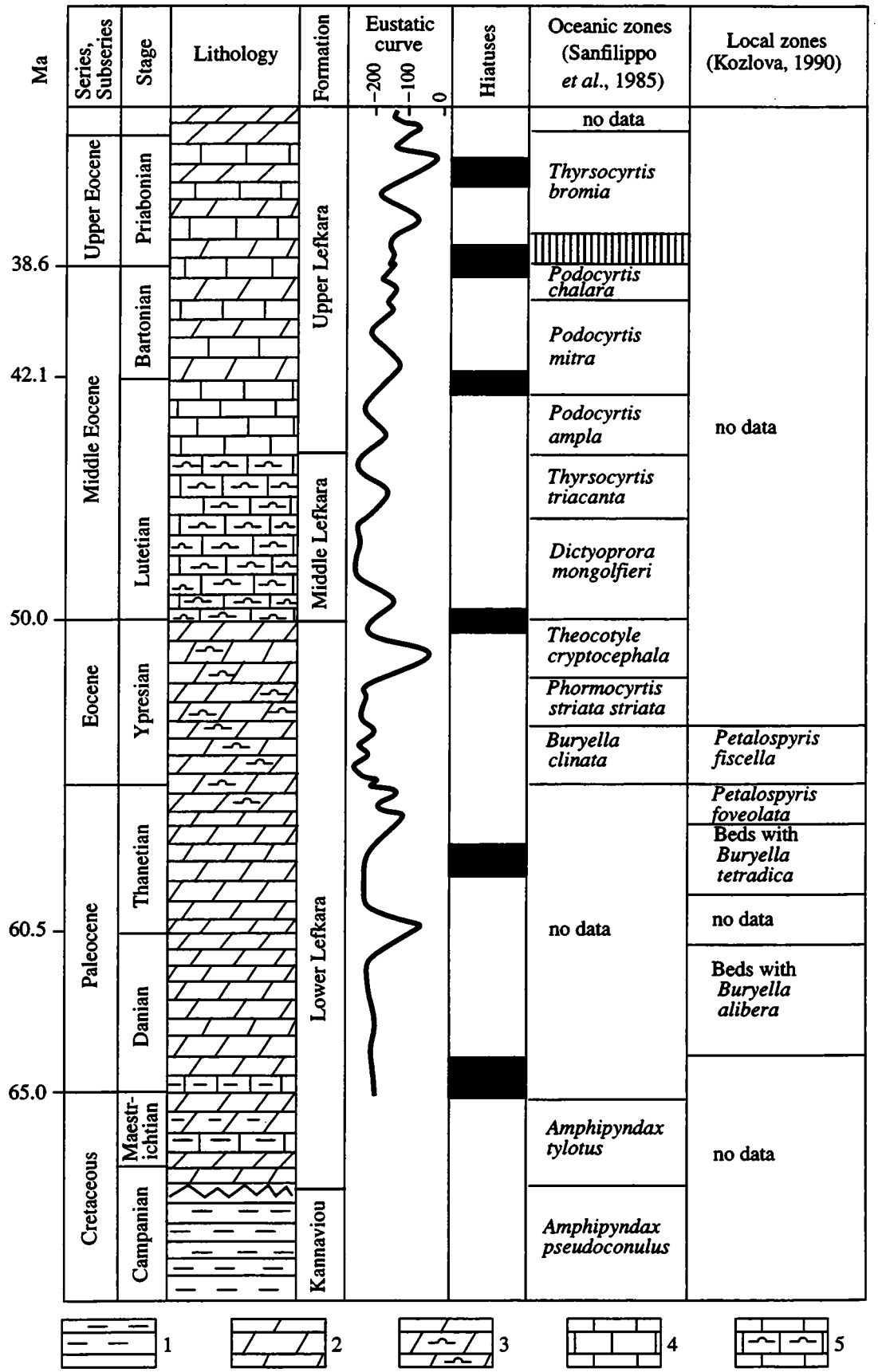

Fig. 2. Radiolarian zones of the Perapedhi section versus the eustatic curve after Haq *et al.* (1987).

1 – bentonitic clays; 2 – marls; 3 – siliceous marls; 4 – limestones; 5 – siliceous limestones.

According to radiolarian zonation, this boundary was suggested to lie within the *Phormocyrtis striata striata* Zone (Foreman, 1973; Sanfilippo *et al.*, 1985), or, in stratigraphic terms, much higher, i.e., inside zones of either *Thyrsocyrtis triacantha triacantha* (Reidel and Sanfilippo, 1978) or *Theocotyle cryptocephala cryptocephala* (Petrushevskaya, 1986).

Krasheninnikov (1978) compiled all the then available data and correlated different zonation schemes for various groups of planktonic fauna. In his opinion, the Lower-Middle Eocene boundary should be placed at the top of the foraminiferal *Globorotalia palmerae* Zone corresponding to the base of the radiolarian *Dictyoprora mongolfieri* Zone. This level is most distinct and well substantiated stratigraphically. An intensive evolution of many Middle Eocene genera and particularly species begins above it, which is why the last boundary position was accepted in this study.

Massive, thick-bedded, light, nonsilisified limestones of the interval under consideration are rich in radiolarians divisible into two zones.

Dictyoprora mongolfieri Zone. Its radiolarians are well preserved and diverse. *Dictyoprora mongolfieri, Theocotyle cryptocephala cryptocephala, Theocorys anaclasta,* and larger *spongodiscids* are its most abundant forms. Specimens of *Spongotrochus radiatus* are characteristic elements of the entire zone. The *Podocyrtis diamesa, Spongotractus pachystylus, Theocotyle fimbria, Thyrsocyrtis hirsuta tensa,* and *Calocycloma ampulla,* as well as *Lithocyrtis vespertilio* and *Thyrsocyrtis rhizodon* typical of the upper part of the zone are common. The assemblage also includes many species registered in temperate Boreal provinces of the Volga River and eastern Urals: *Lophoconus bicorne, Lophophaena sibirica, Amphicraspedum prolixum, Stylosphaera* aff. *irinia, St. coronata,* and *Clathrocyclas elegans.* The zone base is marked by the appearance of the species *Theocorys anaclasta, Spongotrochus radiatus,* and *Theocotylissa fimbria,* and by an increasing number of *Dictyoprora mongolfieri* specimens. All the mentioned cold-water forms along with *Theocorys cryptocephala cryptocephala* become extinct at the unit's top. It is also remarkable that smaller spyrids (e.g., *Petalospyris fiscella* and *P. septenaria*), very abundant in the Upper Paleocene–Lowermost Middle Eocene deposits, disappear just above the upper zone boundary.

Thyrsocyrtis triacantha Zone. Thyrsocyrtis triacantha, Dictyoprora mongolfieri, Lithocyclia aristotelis and genus *Podocyrtis* (*P. papalis, P. phyxis, P. fasciolata*) are dominant among the diverse and well preserved radiolarians. Such forms as *Theocotylissa ficus, Theocampe amphora, Periphaena heliasteriscus, Thyrsocyrtis hirsuta robusta, T. rhizodon, Calocyclas hispida, Lamptonium colymbus, Thecosphaera californica, Lithocyrtis vespertilio, Rhopalocanium ornatum,* and some others are common.

The index species appear at the lower boundary of the zone, and specimens of *Thecosphaera californica, Theocotylissa ficus, Podocyrtis phyxis,* and *Hexalonche senta,* inside it. The *Lithocyrtis vespertilio* and *Stylosphaera* aff. *irinae* forms disappear near the upper boundary.

Upper Lefkara Formation

Podocyrtis ampla Zone. The most characteristic species of this zone include *Podocyrtis ampla ampla, P. fasciolata, Thyrsocyrtis triacantha, T. rhizodon, Eusyringium fistuligerum, Theocampe amphora, Dictyoprora mongolfieri, Spongodiscus phrix, S. communis,* and *Theocotyle cryptocephala nigrini. Lithocyclia aristotelis* and *Theocotylissa ficus* still occur. Specimens of *Podocyrtis ampla ampla* and *Eusyringium fistuligerum Spongodiscus phrix* appearing for the first time mark the zone base, whereas its top is the last occurrence level of the *Theocampe amphora.* This assemblage is to a certain degree less diverse than the previous one and shows typical oceanic features.

The *Podocyrtis mitra* Zone contains a rich assemblage of oceanic radiolarians with abundant *Podocyrtis mitra, Eusyringium fistuligerum, Lychnocanoma bellum, Sethocyrtis triconiscus,* and *Calocyclas asperum.* Other common forms include *Thyrsocyrtis triacantha, Periphaena decora, Podocyrtis papalis, P. diamesa, P. fasciata, Lithocyclia ocellus, Lamptonium colymbus, Cenosphaera eocenica,* and many others.

Such forms as *Cenosphaera eocenica, Artophormis* sp., *Pterocodon tennelus, Haliomma* aff. *melitomma, Sethocyrtis triconiscus,* and *Podocyrtis mitra,* encountered for the first time at the zone base, can be considered, relative to the earlier assemblage, new.

Podocyrtis chalara Zone. Its rich and diverse assemblage contains abundant *Eusyringium fistuligerum, Calocyclas hispida, Sethocyrtis triconiscus, Lychnocanoma tripodium, L. bellum,* and *Calocyclas asperum* forms along with common specimens of *Podocyrtis chalara, Dictyoprora pirum, Cryptoprora ornata, Calocyclas turris, Pterocorythidium barbadensis, Theocampe* sp. 1, *Theocorys* aff. *reticula,* and other radiolarians. Numerous species of *Theocampe* sp. 1, *Theocorys* aff. *reticula, T.* aff. *sporta, Carposphaera globosa,* and *Hexalonche senta,* which are characteristic of upper parts of the *Cycladophora erinacea–Lophophaena macrencephala* Zone, distinguish this assemblage from that of the typical oceanic *P. chalara* Zone. The *Podocyrtis chalara, Dictyoprora pirum, Pterocorythidium barbadense, Cryptoprora ornata,* and *Carposphaera globosa* forms occur right at the zone base, and somewhat higher *Calocyclas turris, Theocampe* sp. 1, *Theocorys* aff. *reticula, Th.* aff. *sporta,* and *Theocotyle venesuelensis* species characteristic of the zone were recorded. Its top is marked by the extinction of *Eusyringium fistuligerum, Podocyrtis papalis, P. fasciolata, P. chalara, Carposphaera globosa, Lophocyrtis jacchia, Cycladophora erinacea, Lophophaena macrencephala,* and *Dendrospyris mitra.* In outcrops of the Perapedhi section, there is the 25-m-high vertical cliff composed of very hard lime-

stones that have not been sampled. This interval evidently corresponds to the upper *Podocyrtis goetheana* Zone of the Middle Eocene, but I cannot prove this with the necessary data.

The thickness of the Middle Eocene deposits is 200 m.

Upper Eocene

The *Thyrsocyrtis bromia* Zone yielded a poor assemblage of well preserved radiolarians. Specimens of *Thyrsocyrtis bromia, Dictyoprora pirum, Calocyclas semipolita*, and *Lychnocanoma bandyca* are dominant among them. The assemblage also contains *Theocorys reticula* and many smaller spyrids. The index species occurring at the zone base disappear along with *Lithocyclia ocellus, Lychnocanoma babylonsis*, and *L. bandyca* at its top.

The thickness is about 60 m.

Oligocene

Soft Oligocene limestones contain radiolarian fauna insufficiently representative for zonation. The Oligocene age of the host deposits is indicated by common *Lithocampe* ex gr. *subligata, Liriospyris clathrata*, and *Dorcadospyris tripodium*. The assemblage is also rich in forms of the *Spongodiscus, Haliometta, Cenosphaera, Theocorys*, and *Prunopyle* genera. Specimens of *Phormocyrtis embolum* sometimes occur in the lower part of this unit. The assemblage differs in generic composition from oceanic groups, probably indicating a change from an oceanic to epicontinental habitat environment. The Oligocene base is marked by first occurrences of *Lithocampe* ex. gr. *subligata* and *Dorcadospyris tripodium* forms. The top level is still undetermined.

CORRELATION OF CYPRUS ASSEMBLAGES TO OTHER COEVAL GROUPS OF RADIOLARIANS

The Paleocene–Eocene radiolarians of the Perapedhi section are to a certain degree similar to their assemblages described by Borisenko (1960a, b) from the Paleocene and Eocene deposits of the Kuban' province, and by Krasheninnikov (1960) from the Eocene sediments of western Ciscaucasia. Still, direct correlation of one to another is impossible, because radiolarians are insufficiently represented in the cited works. In addition, age determinations for Krasheninnikov's assemblages from Ciscaucasia have undergone certain modifications since the 1960s, and now none of them can be compared without problems with any oceanic assemblage of the standard Eocene zonation.

Radiolarian fauna from the Volga River provinces were studied by Kozlova (1984, 1990), who suggested its zonation scheme and published complete lists of species and their micrographs. Correlating coeval radiolarian assemblages from these provinces and from the Perapedhi section, I noted some regularities described below.

Danian deposits bearing radiolarians are extremely rare. In the Perapedhi section, the radiolarian assemblage of this stage includes taxa that are low in diversity. It is distinctly similar to the assemblage of the *Buryella alifera* Zone from the lower Syzran' Beds of the Middle Volga province (Kozlova, 1984, 1990), and to radiolarians discovered in the Tasman Sea by DSDP Leg 21 (Dumitrica, 1973). Common species of these assemblages are represented by *Buryella alifera, Lithocampe* aff. *marinae, Theocotyle auctor, Artostrobus* sp., *Spongodiscus americanus*, and *Stylosphaera coronata coronata*. The age interval of the lower Syzran' beds in the Volga province has not been accurately determined. In the Perapedhi section, these radiolarians occur in association with planktonic foraminifers of the *Turborotalia pseudobulloides, T. trinidadensis*, and *Acarinina unicinata* zones, suggesting the Danian age of their host deposits.

The Lower, and especially Upper Paleocene radiolarian assemblages of Cyprus (those of the *Buryella tetradica* and *Petalospyris foveolata* zones) are very similar to corresponding assemblages from the Volga province. Here, common forms include *Buryella tetradica, Spongodiscus americanus, Theocotyle auctor, Phormocyrtis striata exquisita, Tripodiscinus trilobatus, Petalospyris foveolata, Thecosphaerella rotunda, Th. globulenta, Stylosphaera coronata, Stylotrochus nitidus*, and other species. They comprise more than two thirds of the taxa recognized in the assemblages.

The same is characteristic of the Lower Eocene assemblages from the Middle Volga province and Perapedhi section, which again are very similar and contain such common species as *Buryella tetradica, B. clinata, Phormocyrtis striata exquisita, Petalospyris fiscella, P. tumidula, Spongotrochus paciferus paciferus, Cromyodruppa regularia, Clathrocyclas* aff. *unicum, Lychnocanoma ponderosa, Dendrospyris mitra*, and *Amphicraspedum prolixum*. These forms represent nearly two thirds of the radiolarian species composing the assemblages.

It is likely that most of the species mentioned above do not belong to temperate Boreal forms and can be reffered circumtropical type. The more diverse Middle Eocene assemblages of both the tropical and temperate Boreal provinces contain fewer common species, because tropical radiolarians became dominant in this interval of the Perapedhi section. Common forms, usually occurring in both regions under comparison, include *Stylosphaera* aff. *irinia, Haliomma* aff. *melitomma, Lophophaena sibirica, Thecosphaera eocenica, Spongodiscus communis, Petalospyris septenaria, P. tumidula*, and *Stylosphaera coronata*, composing only about 25% of the Middle Eocene radiolarians.

As it was noted in a series of works (Kozlova and Gorbovets, 1966; Kozlova, 1990; Moksyakova, 1972), the last forms have a wide geographic distribution and probably can be regarded as cosmopolitan.

CONCLUSION

At the beginning of the Paleogene (Danian Stage and the Paleocene time proper), radiolarians of the Perapedhi locality were not very diverse and lacked clear oceanic features in contrast to the Eocene, when they became typically oceanic. The Upper Paleocene deposits of Perapedhi section are divisible into the *Buryella tetradica* and *Petalospyris foveolata* zones of Kozlova's scheme for temperate Boreal provinces. Three units of standard tropical zonation, the *Buryella clinata, Phormocyrtis striata*, and *Theocotyle cryptocephala cryptocephala* zones, have been distinguished within the Lower Eocene interval of the section. It also comprises the *Petalospyris fiscella* Zone of Kozlova's zonation scheme for temperate Boreal provinces. In the Perapedhi section, the *Buryella clinata* and *Petalospyris fiscella* zones are nearly identical in their stratigraphic range. Both probably correspond to a single stratigraphic zone of the Paleogene typical of a vast region entirely comprising tropical and temperate climatic zones of the ancient global ocean, which corresponds to Kozlova's (1984) opinion.

Radiolarian assemblages from both the Middle Volga provinces and Perapedhi locality are most similar at the Lower Lefkara Formation level, i.e., within the Paleocene (silicified marls) and Lowermost Eocene (soft marls with cherts) intervals. This probably was a result of a water mass confluence into a single sea basin comprising all central and marginal provinces of the Tethys of that time. At the beginning of Paleocene, when surface waters were relatively cold and undifferentiated into sublatitudinal climatic zones, radiolarian taxa remained consistent throughout the global ocean. A gradual warming trend of climate typical of the entire Paleocene resulted in the climatic optimum at the beginning of the Early Eocene. Since then, radiolarians became more diverse, and several new genera appeared among them, e.g., *Thyrsocyrtis, Eusyringium*, and *Phormocyrtis*.

At that time, the latitudinal temperature gradient was low. This and direct connections with the Atlantic and Indian oceans made the radiolarian fauna of marginal epicontinental (western Ciscaucasia, Caspian depression, and the Middle Volga) and central (Cyprus) provinces less diverse, but still similar in taxonomic composition. Many characteristic Lower Eocene species of Cyprus, which also occur in the Volga provinces (*Buryella clinata, Petalospyris fiscella, Phormocyrtis striata exquisita, Ph. striata striata, Entapium regulare, Amphicraspedum prolixum, Lychnocanoma ponderosa*, and *Spongotrochus paciferus*) and western Ciscaucasia (previous forms complemented by *Lithomespilus mendosa, Thyrsocyrtis hirsuta hirsuta, T. hirsuta tensa*, and some others), confirm the above assumption. The described Lower Eocene radiolarians from these regions (Borisenko, 1960a; Krasheninnikov, 1960; Kozlova, 1984, 1990) seem to correlate to the tropical zonation scheme.

A cooling at the very beginning of the Middle Eocene resulted in a latitudinal climatic zonation of oceanic areas. Both the surface and deep water temperatures decreased in high and middle latitudes regions (Oberhönsli, in press). The Tethyan basins became divided into two paleogeographic provinces, the tropical and temperate Boreal, each of them having its own temperature regime and water circulation. This gradually caused the taxonomic difference of radiolarian fauna in different provinces. Global transgressions of the Middle Eocene (Fig. 2; Haq *et al.*, 1987) affected the composition of radiolarian fauna in Cyprus. That is why their Middle Eocene assemblages from the Perapedhi section, being indistinguishable from typical oceanic groups of tropical areas, cannot be directly correlated with coeval radiolarian assemblages from the Volga, Caspian, Turgai, and other provinces (Moksyakova, 1972; Zagorodnyuk, 1970; Gorbunov, 1979; Lipman, 1965; and others). A significant regression of the initial Late Eocene period resulted in less taxonomic diversification of radiolarians in the Perapedhi locality.

The Lower Oligocene radiolarians of this locality became so impoverished that it is impossible to apply tropical zonation. Yet the generic composition and several particular species reliably indicate their Early Oligocene age and an evident similarity to the coeval assemblage from the Khadum Horizon of the eastern Ciscaucasia deposits.

Reviewer: L.A. Nevesskaya

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Correlation of Pleistocene Marine and Continental Deposits from the Northwestern Black Sea Region

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Abstract – Fossil remains of small mammals and fresh-water and brackish-water mollusks from liman-marine and alluvial-deltaic deposits of different Pleistocene terraces on the Danube, Prut, and Dniester rivers were studied. Peculiarities of the species composition of therio- and malacofaunas in the region were established. The analysis of paleontologic remains from liman-marine sediments of the northwestern Black Sea region allowed a direct correlation of continental and marine sequences as well as major Pleistocene events on the Russian Plain with those of the Black Sea.

INTRODUCTION

The northwestern Black Sea region is of great interest from the standpoint of Quaternary geology, biostratigraphy, and paleogeography. The region is noted for deposits enriched in fossil remnants of the most stratigraphically important paleontologic groups, i.e., small mammals together with brackish- and fresh-water mollusks. The clearly structured system of the Prut, Danube, and Dniester mouth terraces, which permits the subdivision of sediments not only by paleontologic remains but also by their hypsometric position, is another advantage of the region.

The investigation of Quaternary deposits in the northwestern Black Sea region goes back into the middle of the last century, and was carried out by both Russian and Rumanian researchers, including I.F. Sintsov, N.A. Sokolov, N.I. Andrusov, G.P. Mikhailovskii, A.P. Pavlov, T. Spratt, K. Peters, T. Porucis, N. Makarovici, and others. Systematic comprehensive geologic, geomorphologic, and paleontologic studies were initiated in the postwar period by A.L. Chepalyga, P.F. Fedorov, P.F. Gozhik, K.V. Nikiforova, N.A. Konstantinova, G.M. Bilinkis, P.D. Bukatchik, L.I. Alekseeva, L.P. Aleksandrova, A.I. David, K.A. Tatarinov, K.I. Shushpanov, S.I. Medyanik, R.Ya. Arap, N.N. Volontir, and others.

These investigations allowed us to distinguish the main stratigraphic units and faunal assemblages in this region and to develop a Quaternary stratigraphic scheme for Moldova based mainly on paleontologic material from the Dniester River basin (Aleksandrova *et al.*, 1986). However, few fossil remains were available from Pleistocene deposits of the Danube and Prut lower reaches. Moreover, paleontologic, especially theriologic, records from alluvial-deltaic and liman-marine sediments of the Middle and Late Pleistocene were lacking. This prevented the development of a detailed reconstructions of Quaternary mammalian and molluscan fauna evolution in the northwestern Black Sea region and hampered their correlation with thoroughly developed biostratigraphic scales referring to the central Russian Plain.

Beginning in 1980, we initiated an intensive field search for new localities of Pleistocene therio- and malacofaunas in liman and alluvial-deltaic deposits of the Danube, Prut, and Dniester lower reaches. This resulted in the discovery of several rich small mammal and mollusk localities, and provided additional paleontologic material from the previously known sites.

The richest molluscan and mammalian remains were found in the Danube lower reach, where the Black Sea transgressions penetrated repeatedly. This led to the formation of vast semi-isolated lagoons, whose deposits are still preserved in the Danube mouth terraces and in shore scarps of recent Danube limans.

Thus, major genetic types of sediments, i.e., subaerial, alluvial-deltaic, and liman-marine ones, comprise the terrace sequences in the region. Liman deposits, a connecting link between continental and marine sequences, are of special importance.

BRIEF CHARACTERIZATION OF RIVER TERRACES IN THE NORTHWESTERN BLACK SEA REGION

Seven Quaternary terraces were distinguished in large river valleys of the region (Chepalyga, 1962; Konstantinova, 1963; Aleksandrova *et al.*, 1986). Deposits of the VII (Karagach), VI (Nagornoe), and V (Uzmari) Prut and Danube terraces, 65 - 70, 55 - 60, and 45 - 50 m high, respectively, are referred to the Early Pleistocene. In the Prut River mouth, the base of terraces is located at 23 - 25 m (terrace VII), 20 - 22 m (terrace VI), and 16 - 18 m (terrace V) gradually lowering southwards.

Terrace IV (Babel'), 35 - 40 m high on the east shore of Yalpug Lake, the Danube River basin, with the base at 1 - 2 m, is referred to the Middle Pleistocene. In the Prut River valley, terrace IV (Dzhurdzhuleshty) is 40 - 45 m high, its base is 7 - 8 m. Terrace III (Reni), at a height of 25 - 30 m and 20 m in the Prut and Danube basins, respectively, was formed in the second half of the Middle Pleistocene. The height of the terrace base decreases in the same direction from 6 m in the Prut River mouth to 2 m on the east shore of the Katlabukh Lake, Danube River basin.

Terraces II (Orlovka) and I (Novoselovka) are referred to the Late Pleistocene. Reference sections of all Pleistocene terraces are presented in the figure; Mikhailesku and Markova (1992) comprehensively described them.

EARLY PLEISTOCENE SMALL MAMMAL AND MOLLUSK FAUNAS

Sediments of the Danube terrace VII are exposed in shore scarps of the Kakhul Lake, northwards from the village of Nagornoe (refer to the figure, a) and Limanskoe. They are represented by alluvial-deltaic and liman-marine deposits yielding mollusk shells of *Didacna baerictassa* Pavl., *D. pseudocrassa* Pavl., *Monodacna subcolorata* Andrus., *Dreissena polymorpha* Pall., and *Viviparus tiraspolitanus* Pavl., as well as small mammals *Mimomys hintoni* Fejfar, *Mimomys intermedius* Newton, *Prolagurus pannonicus* Kormos, *Microtus* (*Stenocranius*) *hintoni* Kretzoi, and others.

The brackish-water mollusk assemblage correlates the subaqueous sequence of the VII Danube terrace with Lower Chaudian deposits from Cape Chauda, the Kerchenskii Peninsula, and Lower Bakuan sediments from the Cape Litvin, the Tamanskii Peninsula. The latter locality, along with mollusk shells of *Didacna baericrassa* Pavl., *D. rudis* Nal., *D. parvula* Prav., *Monodacna subcolorata* Andrus., and *Viviparus tiraspolitanus* Pavl., yields the following forms of the Early Tiraspol' small mammalian fauna: *Lagomorpha–Ochotona* sp., of *Rodentia–Allactaga* sp., *Mimomys* sp., *Villanyia fejervaryi* (Kormos), *Eolagurus simplicidens gromovi* Topac., *P. praepannonicus* Topac., *Prolagurus pannonicus* Kormos, *Microtus* (*Pitymys*) sp., *M.* (*Microtus*) *arvalinus* Hinton, and *Microtus* sp.

The Cape Litvin fauna correlates with that of the Early Tiraspol' from the Shamin locality on the Don River and may be referred to the earliest faunas of the Tiraspol' assemblage (Markova, 1992). Sediments enclosing these faunas probably correspond to the terminal formation phase of the Mikhailovka (Balashevo) fossil soil from the periglacial sequence of the Russian Plain (Velichko *et al.*, 1992). In Western Europe similar faunas were found in Hungary, Rumania, and Germany, in Villany 6, Betfia 7, and the Mahlis localities, respectively (Kretzoi, 1956; Fuhrmann *et al.*, 1977; Terzea and Jurasak, 1969).

In the Dniester valley sediments under consideration correspond to the alluvium of terrace VII (Mikhailovka), where the Brunhes–Matuyama reversal occurs in the lower part (Trubikhin and Chepalyga, 1982).

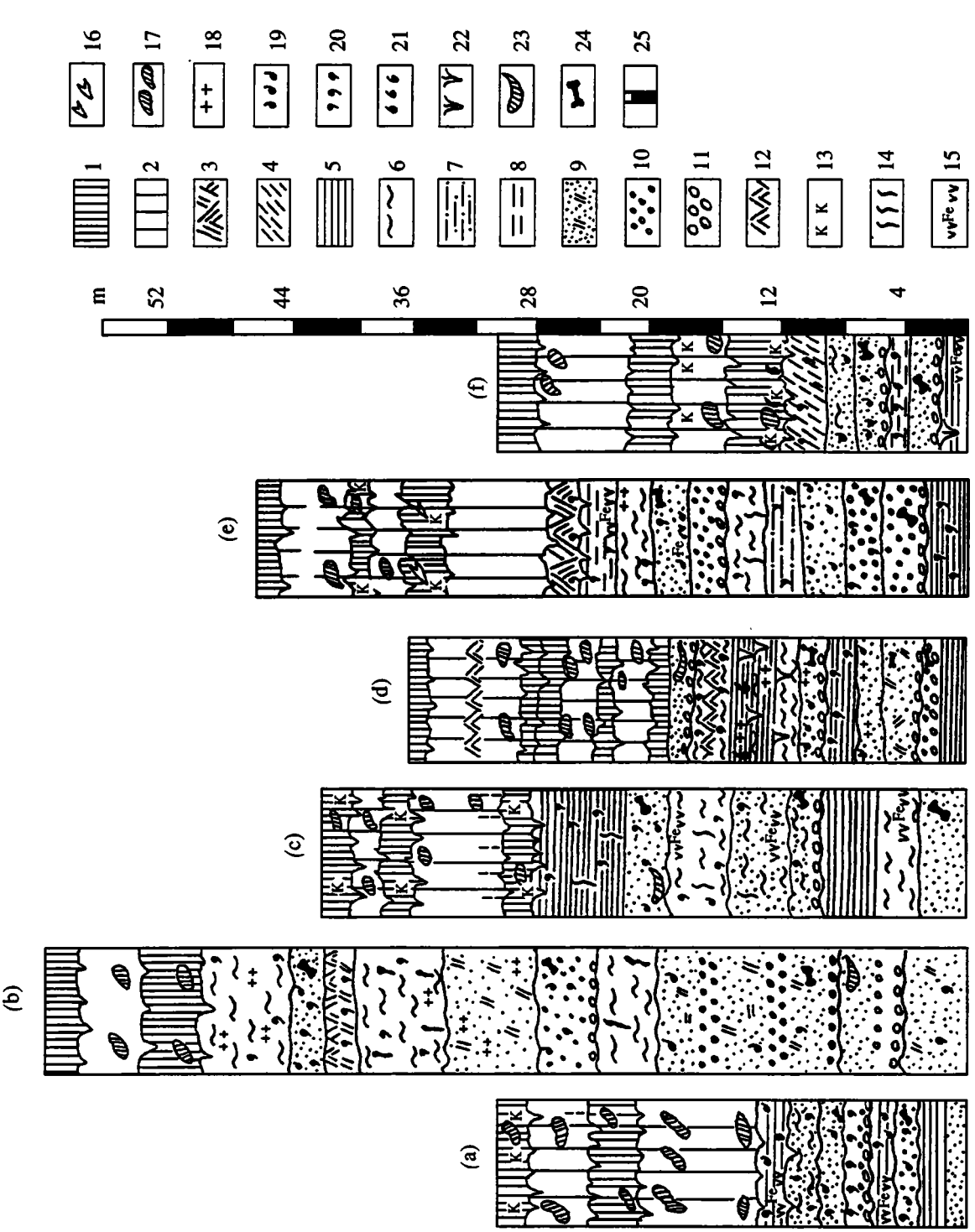
We studied deposits of the VI Danube terrace in the vicinity of Limanskoe, Nagornoe (southern outskirts, refer to the figure, b), Dolinskoe, Priozernoe, Starye Troyany, and other localities. They yield abundant fresh-water mollusks of the Tiraspol' assemblage: *Potomida litoralis* (Cuv.), *Crassiana crassa* Phil., and *Viviparus tiraspolitanus* Pavl., as well as the Chaudian brackish-water species *Tschaudia tschaudae* Andrus., *Didacna* aff. *pseudocrassa* Pavl., *Dreissena tschaudae* Andrus., and others.

The presence of listed species correlates the liman-marine deposits from this terrace with the Upper Chaudian sediments of Cape Chauda. Such a correspondence is confirmed by the occurrence of the ostracods *Potamocypris tschaudae* (Schn. et Neg.), *Cyprideis littoralis* (Brady), *Tyrrhenocythere amnicola donetziensis* Dub., and others (Mikhailesku and Markova, 1992).

The small mammal assemblage from terrace VI includes *Mimomys intermedius* Newton, *Prolagurus* ex gr. *pannonicus* Kormos–*posterius* Zazhigin, *Microtus* (*Stenocranius*) *hintoni* (Kretzoi), *M.* (*S.*) *gregaloides* (Hinton), *M.* (*Microtus*) *oeconomus* Pall., and *M.* (*M.*) *arvalinus* Hinton.

The evolutionary level of small mammalian and fresh-water molluscans faunas allows us to correlate the subaqueous deposits of the VI Prut and Danube terrace and the alluvium of the VI Kolkotov Dniester terrace, which yields fossils of the following rodents in the Tiraspol' faunal stratotype (the Kolkotova Balka section near Tiraspol'): *Allactaga* sp., *Spalax* sp., *Cricetus* sp., *Clethrionomys* cf. *glareolus* Schreber., *Ellobius* sp., *Mimomys intermedius* Newton, *M. majori* Hinton, *Prolagurus posterius* Zazhigin, *Lagurus transiens* Janossy, *Eolagurus* cf. *luteus* Eversmann, *Pitymys hintoni* Kretzoi, *P. gregaloides* Hinton, *P. arvaloides* Hinton, *Microtus arvalinus* Hinton, *M.* cf. *nivaloides* F. Major, and *M. ratticepoides* Hinton (Aleksandrova, 1976). Similar faunas were also recorded in the Klepki, Novokhopersk I and II, Uryv IV, Moiseevo III, and Korostylevo I (the Don River basin) localities (Markova, 1982; Agadzhanyan, 1992; Krasnenkov and Agadzhanyan, 1975; Krasnenkov *et al.*, 1984) and were referred to the top of the Il'inka small mammalian subcomplex. These localities correlate with the Rzhaksa soil–loess complex from the periglacial sequence of the Russian Plain (Breslav *et al.*, 1992). In Western Europe, faunas from the West Runton (England), Somssish-hegy and Kovesvarad (Hungary), Hohen-Sulzen and Voigtstedt (Germany), Podumci I (Yugoslavia), and other localities correspond to this interval (Hinton, 1926; Janossy, 1983; Kahlke, 1965; Storch *et al.*, 1973; Malec and Rabeder, 1984).

Deposits of the V Prut and Danube terrace are exposed in the areas of the Dzhurdzhuleshty (refer to the figure, c), Kyshlitsa–Prut (eastern outskirts), Slobodzeya-Mare, Utkonosovka, Ripa Skortsel'skaya, and



Lithology of reference sections of the Quaternary Danube terraces.

(a) – Section of terrace VII in the northern outskirts of Nagornoe; (b) – section of terrace VI in the southern outskirts of Nagornoe; (c) – section of terrace V in the northern outskirts of Dzhurdzhuleshty; (d) – section of terrace IV near Ozernoe; (e) – section of terrace III near Plavni; f – section of terrace II near Novonekrasovka.

1 – fossil and recent soils; 2 – loesslike loams; 3 – hydromorphic soils; 4 – subaqueous loams; 5 – clays; 6 – silts; 7 – loamy sands; 8 – horizontally bedded sands; 9 – grits; 10 – pebbles, gravel; 11 – boulders; 12 – gleying; 13 – carbonates; 14 – Fe-Mn concretions; 15 – ferruginization; 16 – gypsum druses; 17 – mole-courses; 18 – ostracods; 19 – brackish-water mollusks; 20 – fresh-water mollusks; 21 – land mollusks; 22 – bioturbation; 23 – large mammal remnants; 24 – small mammal remnants; 25 – scale, m.

Suvorovo villages (middle and upper beds). They are characterized by abundant and diverse mollusk fauna including *Didacna baericrassa* Pavl., *D. poratica* Mih., *Monodacna subcolorata* Andrus., *Dreissena rostriformis* (Desh.), *D. polymorpha* Pall., *Corbicola fluminalis* Mull., *Viviparus tiraspolitanus* Pavl., *Theodoxus danubialis* Pfeif., and *Fagotia esperi* Fer., as well as by the following Rodentia remnants: *Mimomys intermedius* Newton, *Prolagurus pannonicus* Kormos, *P. posterius* Zazhigin, *Lagurus transiens* Janossy, *Microtus (Terricola) arvalidens* Kretzoi, *M. (Microtus) arvalinus* Hinton, *M. (M.) oeconomus* Pall., *M. (Stenocranius) gregaloides* Hinton, and *M. (S.) gregalis* Pall. These faunas still contain a great deal of ancient components characteristic of the early and developed Tiraspol' faunas. However, numerous remains of *Microtus (Stenocranius) gregalis* were first discovered there. *Lagurus transiens* dominated the lagurids. Faunas of this evolutionary stage are widely known on the Russian Plain and correspond to the Muchkap interglacial (Velichko *et al.*, 1984; Agadzhanyan, 1992; Markova, 1982, 1992). In the periglacial sequence of the Russian Plain that time is marked by the Vorona fossil soil horizon. In the Kolkotova Balka section, the Dniester River basin, numerous fossil rodents of a Late Tiraspol' appearance were derived directly from this soil horizon (Mikhailesku and Markova, 1992). Faunas of the same evolutionary stage were distinguished as the Muchkap small mammalian subcomplex (Breslav *et al.*, 1992).

These faunas yield the brackish-water Chaudian mollusks *Didacna baericrassa* Pavl. and *Monodacna subcolorata* Andrus., which indicate the Early Pleistocene age of the Danube, Prut, and Dniester terraces. At the same time, in contrast to the fauna of terrace VI, first Drevneeuxinian forms, namely, *D. poratica* Mih., appear there. Among the fresh-water mollusks, together with the last *Viviparus tiraspolitanus* Pavl., first occurrences of *Corbicula fluminalis* Mull. are recorded. The studied terrace level can be conventionally correlated with the Earliest Drevneeuxinian basin of the Black Sea, namely, the Krinitsa, Ureki, and, possibly, Platovo sections (Fedorov, 1978).

MIDDLE PLEISTOCENE SMALL MAMMAL AND MOLLUSK FAUNAS

Deposits of terraces IV and III in the studied region are referred to the Middle Pleistocene. Terrace IV (Babel') is 35 - 40 m high, whereas its base is not more than 10 m high at the mouth of the Prut River, decreasing southwards. The subaqueous sequence of the terrace is exposed to the south at Kyshlitsa–Prut, Limanskoe, and Ozernoe. The analogous deposits occur lower than sea level in the Danube River delta, as well as in Rumania near Galac, Tuluchest, Berbosh, Stoikan, Frudlushitsa, Independentsa, and in other localities (Macarovici and Costetchi, 1973). According to brackish-water mollusks including *Didacna pontocaspia* Pavl., *D. poratica* Mih., and others, liman-marine deposits of Danube terrace IV correlate well with those of the Drevneeuxinian terrace on the Caucasian (Cape Kadosh) and Tamanian (Dinskii Bay, Malyi Kut, Il'ich, and other localities) coasts, as well as on the Azov coast (Bessergenovka, Taganrog, and others). The fossil rodent assemblage from the Ozernoe locality (refer to the figure, d) includes *Arvicola cantiana* Hinton, *Eolagurus luteus volgensis* Alex., *Lagurus transiens* Janossy, *Microtus (Terricola) arvalidens* Kretzoi, *M. (Microtus) arvalinus* Hinton, *M. (M.) oeconomus* Pall., and *M. (Stenocranius) gregalis* Pall. This fauna indicates a new evolutionary stage: it lacks the ancient root-toothed voles *Mimomys* and *Villanyia*, as well as the archaic steppe lemming *Prolagurus*. The archaic water rat *Arvicola cantiana* found at this level for the first time was the most characteristic form of these faunas. Steppe lemmings were represented mainly by *Lagurus transiens*, though the *Lagurus lagurus* morphotype already constituted approximately one third of the remnants.

Faunas of the same evolutionary level correspond to the Singil' (Gun'ki) assemblage and are widely known on the Russian Plain. They were recorded at Gun'ki, Chigirin, Pivikha (the Dnieper River basin), Verkhnyaya Emancha, Vladimirovka I and II, Strelitsa (the Don River basin), Chekalin (gyttja, the Oka River basin), Rybnaya Sloboda (the Kama River basin), and other localities (Markova, 1992; Agadzhanyan and Erbaeva, 1983). These faunas correlate with the Likhvin interglacial, which is confirmed by the occurrence of rodent localities yielding *Arvicola cantiana* in the sediments with typical Likhvin pollen spectra. Similar fauna was found in the Inzhavino fossil soil horizon of the Kolkotova Balka section near Tiraspol' (Mikhailesku and Markova, 1992). In Western Europe microtheriofaunas of the same evolutionary stage were described from the following localities: Sussenborn, Mosbach, Erpfingen, Petersbuch, and Sudmar-Berg in Germany; Ostend in England; Isernia la Pineta in Italy; and some other localities (Kahlke, 1965; Koenigswald, 1970, 1972; Sala, 1983; Sutcliffe and Kowalski, 1976).

Sediments of Danube terrace III (Reni) are exposed between Dzhurdzhuleshty and Reni, as well as in shore scarps of Lake Yalpug, north of Plavni and Novonekrasovka (refer to the figure, e), and Lake Kakhul, and Orlovka and Limanskoe. The terrace is 25 - 30 m high with the base located at a level of 3 - 6 m in the Reni area. Subaqueous deposits of Danube terrace III contain the small mammalian fauna with *Arvicola chosaricus* corresponding to the Khozar faunal assemblage, and the Uzunlar lagoon assemblage of brackish-water mollusks with *Didacna uzunlarica* Tschep. et Mih. and *D. poratica* Mih. together with the Middle Pleistocene ostracods and fresh-water mollusks (Mikhailesku, 1990; Mikhailesku and Markova, 1992).

The microtheriofauna of a similar evolutionary stage was described from the stratotype of the Khozar faunal assemblage near the village of Chernyi Yar on the lower Volga River (Aleksandrova, 1976), and from the Uzunlarian stratotype at Lake Uzunlar, the Kerchenskii Peninsula (Chepalyga *et al.*, 1986). In the latter

section, along with the above-mentioned brackish-water mollusks, the following Mediterranean forms were found: *Cerastoderma glaucum* (L.), *Scrobicularia plana* Costa, *Bithium reticulatum* Costa, *Nassarius reticulatum* L., *Mytilaster lineatus* Gm., *Corbula mediteranea* Mil., *Arba ovata* Phil., *Balanus* sp., and others. The deposits also yield a diverse ostracode fauna with *Callistocythere mediteranea* (Mull.), *C. abjecta* Schorn., *C. quinquetuberculata* (Schorn.), *C. lopatici* (Schorn.), *Amnicythere cymbula* (Zik.), and *Loxoconcha immodulata* Step. The Plavni locality at the northern outskirts of the village and the Uzunlar section contain the small mammals *Arvicola chosaricus* Alex., *Lagurus* ex gr. *lagurus* Pall., *Microtus arvalis* Pall., *M. oeconomus*, *M.* (*Stenocranius*) *gregalis* Pall., and others.

LATE PLEISTOCENE SMALL MAMMAL AND MOLLUSK FAUNAS

Sediments of terraces II (Orlovka) and I (Novoselovka) on the Danube and other rivers of the southwestern Black Sea region are referred to the Late Pleistocene. Terrace II is 14 - 18 m high having a socle level ranging from +1 - +2 m near Reni to –1 - –2 m near Izmail. Subaqueous deposits of terrace II are exposed in the vicinity of the Orlovka, Novonekrasovka (refer to the figure, f), Vladycheny, Plavni, and Kosa villages, and are characterized by the Karangat lagoon assemblage of brackish-water mollusks with *Didacna danubica* Mih., *D.* cf. *ultima* Popov, and others. They also yield forms of the Shkurlat small mammalian assemblage, i.e., *Arvicola* ex gr. *terrestris* L., and *Microtus arvalis* Pall. (Mikhailesku and Markova, 1992).

According to the mollusk fauna, the liman-marine sequence of terrace II correlates well with the sediments of the Karangatian terrace of the Black Sea, which are exposed in the Gudauta, Chushka, and Kazantip sections, as well as in the lower part of the El'tigen section. In the latter exposure Karangatian beds contain the small mammals *Arvicola* ex gr. *terrestris* L., *Lagurus lagurus* Pall., *Microtus arvalis* Pall., and *Microtus* (*Stenocranius*) *gregalis* Pall. Faunas of this evolutionary stage are known mainly from the Shkurlat, Gadyach, Chernyanka, Malyutino, and Mikhailovka-5 localities of the central Russian Plain, where they were referred to the Shkurlat faunal assemblage (Alekseeva, 1980; Markova, 1992; Agadzhanyan and Glushankova, 1986). According to geological data, mammalian localities of the Shkurlat faunal assemblage correlate with the Mikulino interglacial. During this interglacial the Salyn' fossil soil of the Mezin soil complex was formed on the Russian Plain (Velichko *et al.*, 1984, 1992). In Western Europe, mammalian faunas from Aveley, Grey Terrok, and Illford in England, Taubach in Germany, and other localities correspond to this period (Sutcliffe and Kowalski, 1976; Kahlke, 1961).

Sediments of terrace I are exposed in the Danube River basin southward from the villages of Novoselskoe, Orlovka, and Bogatoe, where it is 8 - 10 m high and its base lies at a depth of –13 - –17 m. Subaqueous deposits of the terrace yield both fresh- and brackish-water mollusks: *Monodacna pontica carinata* Grossu et Baltac., *Dreissena polymorpha* Pall., *Hypanis fragilis* Mil., *Turricaspia* (*Micromelania*) *lincta* (Mil.), *Viviparus fasciatus* Mull., and others. The fauna from liman-marine deposits of terrace I is characterized by the absence of *Didacna* Eichwald, which, evidently, dissapeared during the Novoeuxinian regression due to a strong freshening of the Black Sea (Mikhailesku, 1990; Mikhailesku and Markova, 1992).

HOLOCENE MALACOFAUNAS

In the lower Danube valley the Holocene high (up to 5 - 6 m) and low (up to 1.5 - 2 m) terraces are very distinct. Their deposits contain relicts of the Novoeuxinian brackish-water mollusks *Monodacna, Hypanis, Dreissena*, and *Turricaspia* together with recent fresh-water mollusks. In the Danube River delta area, sediments of the high and lower flood-plain correspond to the Drevnechernomorian and Novochernomorian deposits with the Mediterranean fauna. They compose a characteristic of the Danube delta "grinda", i.e., preserved sand bars of the ancient shoreline stretched along the recent shore, though 15 - 20 km away from it.

CONCLUSION

Thus, the study of fossil small mammals occurring together with brackish- and fresh-water mollusks in Pleistocene localities from liman-marine and alluvial-deltaic deposits in the southwestern Russian Plain allowed us to correlate major events in the Black Sea basin and Russian Plain. Because the paleontologic localities are associated with sediments of transgressive phases of the Black Sea basin caused by glacioeustatic sea level fluctuations, which in turn resulted from climatic changes, the studied material corresponds to significant Pleistocene warmings, i.e., interglacials. Glacial epochs may be characterized by materials from other types of sediments, mainly from loess horizons.

(1) Localities from subaqueous deposits VII river terraces in the southwestern Russian Plain correspond to the beginning of the Pleistocene, with the Brunhes-Matuyama reversal occurring at the base of the subaqueous sequence. They yield brackish-water mollusks characteristic of the Early Chaudian transgression and bone remains of small mammals corresponding to Early Tiraspol' faunas. Based on the correlation with small mammals from other regions of the Russian Plain, we can probably refer these sediments to the terminal formation phase of the Mikhailovka (Balashovo) soil from the periglacial sequence of the Russian Plain (Velichko *et al.*, 1992).

(2) Localities containing younger Chaudian mollusk fauna were reliably correlated with the Upper Chaudian malacofauna from the Cape Chauda deposits, together with the typical Tiraspol' small mammalian faunas

associated with the subaqueous deposits of terrace VI in the region. The analysis of data on combined therio- and malacofaunal localities allows us to correlate this Chaudian transgression phase with the Kolkotov (Rzhaksa) fossil soil formation period in the Russian Plain, as well as with the Il'inka interglacial (Breslav *et al.*, 1992).

(3) Localities yielding the Latest Tiraspol' faunas and a peculiar mollusk assemblage with both Chaudian and Drevneeuxinian forms were found in liman-marine and alluvial-deltaic sediments of river terrace V in the northwestern Black Sea region. Paleontologic records date these deposits at the second half of the Early Pleistocene and refer them to the Muchkap interglacial according to microtheriologic data. In the periglacial sequence of the Russian Plain, the Vorona fossil soil horizon corresponds to this period.

(4) Findings from subaqueous deposits of terrace IV enabled us to distinguish a new evolutionary stage for small mammalian and molluscan faunas. Small mammalian faunas of this age reliably correlate with the Singil' (Gun'ki) faunal assemblage, whereas malacologic materials, with the Drevneeuxinian Black Sea faunas. This allows us to refer the sediments to the Likhvin interglacial and to correlate them with the Inzhavino fossil soil, as well as to the time of the Drevneeuxinian Black Sea transgression.

(5) Subaqueous deposits of terrace III are characterized by small mammalian faunas corresponding to the Khozar faunal assemblage and brackish-water mollusks of the Uzunlar lagoon assemblage. In the periglacial loess–soil series on the Russian Plain, these sediments correlate with post-Likhvin Middle Pleistocene soil horizons, namely, the Kamenka and Romny soils, which were formed during warmings that occurred between the Likhvin interglacial and the Dnieper glaciation (Velichko *et al.*, 1992).

(6) Finally, the beginning of the Late Pleistocene is characterized by paleontologic materials from subaqueous deposits of terrace II, which yield forms of the Shkurlat small mammalian assemblage and brackish-water mollusks characteristic of the Karangat Black Sea transgression. These deposits may be referred to the Mikulino interglacial and the Salyn' phase of the Mezin soil complex formation.

As mentioned above, all the studied small mammalian faunas are of an interglacial type. The predominance of open landscape forms is due to the southern position of the region. Palynologic records from the liman and alluvial-deltaic Pleistocene deposits of the southwestern Black Sea region also indicate the interglacial type of vegetation that occurred during these periods. During the interglacial warmings of the Early, Middle, and Late Pleistocene, the vegetation was mainly of a forest-steppe type. According to palynologic data, during coolings (glaciations) steppe landscapes of a periglacial character prevailed in the Middle and Late Pleistocene (Medyanik and Mikhailesku, 1992).

Thus, numerous new therio- and malacofaunal localities in liman-marine and alluvial-deltaic deposits in the northwestern Black Sea region not only made it possible to establish the peculiarities of the species composition of small mammals together with brackish- and fresh-water mollusk assemblages and to elucidate their main ecologic characteristics, but may serve as the basis for the correlation of marine and continental sediments in the region. This in its turn allows us to correlate major Pleistocene events in the Black Sea basin and on the Russian Plain.

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Reviewer: M.A. Akhmet'ev.

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PERSONALIA

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In 1993, the hundredth birthday of J.A. Dalinkevichius, a student, then lecturer at the St. Petersburg Mining Institute, and later a professor at the Kaunas and Vilnius universities, was observed. J.A. Dalinkevichius was the founder of geoscience in Lithuania, compiling and publishing geological maps of Baltic republics, and educating the present generation of Lithuanian geologists.

The scope of his scientific studies was extraordinarily wide. He was concerned with paleontology, stratigraphy, tectonics, paleobiogeography, Quaternary geology, geological engineering, geomorphology, mineral resources, etc.

J.A. Dalinkevichius was born on June 13, 1893, to a peasant family living near Ukmerge, 70 km from Vilnius. In 1903 he entered gymnasium in Grodno and graduated with the silver medal in 1911.That year he became a student of astronomy in the Faculty of Physics and Mathematics of St. Petersburg University, and a year later entered the St. Petersburg Mining Institute. Here he attended lectures by professors V.I. Bauman, V.S. Fedorov, N.S. Kurnakov, P.I. Stepanov, A.A. Borisyak, K.I. Bogdanovich, and other famed Russian scientists, and later told his students much about them. After graduating the Mining Institute, J.A. Dalinkevichius became an assistant at the institute's department of Geodesy and Mine Surveying. In 1923 he published the textbook on "Mining Geometry." During his time as a student and assistant, J.A. Dalinkevichius participated in many geological expeditions to Estonia (1913), the Crimea (1916), Kazakhstan (1917), Timan (1919), Karelia (1920), and the Donetsk basin (1922 - 1923).

In 1924, J.A. Dalinkevichius returned to Lithuania to work first as laboratory technician, and then as an assistant in the Department of Geology and Mineralogy of Kaunas University. Due to studies taken at his initiative, he published several papers on geology and mineral resources including the well known work on the Devonian in Lithuania.

In 1932 - 1933, J.A. Dalinkevichius went abroad to visit Austria, Germany, Belgium, France, Italy, and Yugoslavia on a scientific tour. Visiting Graz University in 1933, he defended his Ph.D. thesis entitled: "Tertiary Deposits of the Shventoiya River Valley." During the next period (1934 - 1940), he taught at Kaunas University, proceeded with his geological investigations, and published more than 20 works on the geology of Lithuania.

When the Chair of Geological Engineering was organized in the Kaunas University in 1940, J.A. Dalinkevichius was nominated its Head and was given the Chair. Then in 1941, he was nominated as Director of the Institute of Geology of the Lithuanian Academy of Sciences, when it was organized for the first time in Soviet Lithuania. In 1946, he was elected a Corresponding Member of the Lithuanian Academy of Sciences.

After the World War II, an intensive training of specialists, including geologists, was initiated in Soviet Lithuania, as in the rest of the USSR. From that time, J.A. Dalinkevichius concentrated his scientific and teaching activity at the Chair of Geology of Vilnius

University. He was its head from 1944 to 1963, and then became a consulting professor. His lectures on historical geology were so picturesque that the audience sometimes were under the illusion that they were not in the lecture hall, but on the Cambrian sea floor among various trilobites, or in the forest of the Carboniferous period between giant lepidodendrons and ferns. Hearing this lectures was like travelling back in geological time. Lecturing on the regional geology of the USSR, J.A. Dalinkevichius paid much attention to the advances of Russian and Soviet geologists, and spoke of forthcoming tasks. Concerned with various branches of geology, he always accented that paleontology and stratigraphy are its principal base, and therefore must be learned by any geologist. That is why many of his students became paleontologists and stratigraphers, among them such famed scientists as J.J. Pashkevichius, A.A. Grigelis, V.N. Talimaa, M.V. Kabailene, P.I. Suveizdis, and others. They all started their paleontological studies under the guidance of J.A. Dalinkevichius.

Besides his lectures, prof. J.A. Dalinkevichius concerned himself with the work of the student's Geological Society, where students learned much about his geological expeditions. Often he was their leader in geological excursions to bedrock outcrops and to reference bore hole sites to observe core samples and to classify fossils together with students.

During his last years, J.A. Dalinkevichius was very interested in astronomy, as he was when he was at the school. He arranged his own well equipped observatory on the top floor of his house in Kaunas. There a powerful telescope, portraits of prominent astronomers, N. Copernicus, I. Newton, W. Herschel, and others, and many books on astronomy in Lithuanian, Polish, Russian, English, and German – he knew all these languages fluently – held court as he gazed into the starry sky. A large library on geology and the professor's working room were on the second floor. The first and ground floors were left for the kitchen, dining room, and rooms for family and guests.

Professor J.A. Dalinkevichius died in Kaunas, February 26, 1980. He is buried near Ukmerge, in the cemetery of his birth place, the village of Pamushio. His students will always remember their Professor, and will continue his investigations.

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